The importance of backsheet quality for PV module longevity

Carrie Xiao, PV Tech China, translated by Huangye Jiang

ABSTRACT
Certain PV modules have begun showing signs of yellowing, a consequence of backsheet deterioration. This phenomenon can impact on power plant performance and safety, and is emerging as a potential problem waiting to happen with low-cost modules. This paper explores the key attributes of backsheets and assesses the relative benefits of the different types of backsheet on the market and the materials used in them. The different tests undertaken for backsheets are reviewed, and arguments are put forward for the requirement of a standardized testing regime for this crucial module component.

Introduction

Setting: a solar plant in Europe. The owner walks to the edge of the plant, and finds the PV modules are exhibiting a yellowish colour instead of the expected bright silver (see Fig. 1). Why had these supposedly good-quality modules changed colour? The owner queries the supplier, who replies: "It's perfectly normal – it's just like when people get tanned after long hours of sunbathing, no matter how much suncream they apply."

This does not relieve the owner's worries, so the supplier replaces the batch of modules that are most severely affected by the yellowing condition. In a subsequent analysis of the faulty modules, the source of the yellowing becomes clear: a key encapsulation material – the backsheet.

> "The appearance of yellowing of a module is a forewarning of cracking."

"For the most part, the appearance of yellowing of a module means a reduction in its transparency, and at the same time it is a forewarning of cracking," says David Li, sales manager of PV backsheet specialty products at Honeywell. "Backsheet yellowing is a widespread phenomenon, mostly found in areas of strong sunshine, such as Spain. The use of non-UV-proof EVA and backsheets leads to accelerated ageing; the module then takes on a yellowed appearance, affecting its lifetime."

Mr. Wei, the product manager at HT-SAAE (Shanghai Aerospace Automobile Electromechanical Co., Ltd.), has visited several plants in Europe, and confirms that many operators have encountered similar problems.

Conrad Burke, DuPont PV Solution's marketing director, bluntly warns: "Backsheets play an essential role in protecting modules; they are the electrical insulator between the modules and the surrounding environment. Defective modules could result in major disasters, cause unexpected power attenuation and compromise safety. Such a huge consequence may have a damaging effect on brand reputation, and even endanger human lives, and the issue needs to be given sufficient attention."

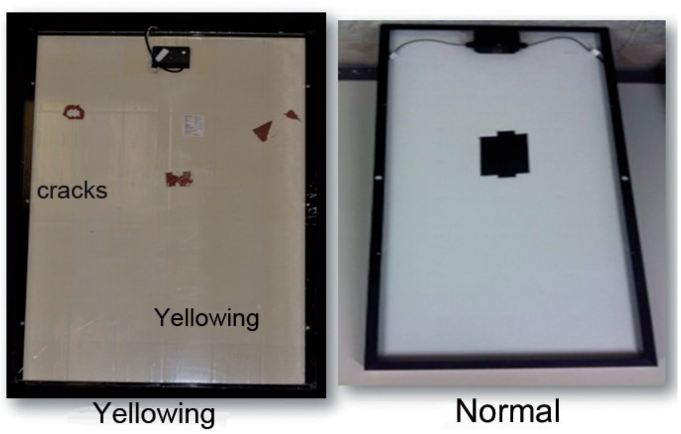

Figure 1. Yellowing and cracking of a PV module.

Ensuring the safety of modules and plants

Similarly to human beings, modules need to fight against ageing from UV. The light-induced degradation (LID) of modules must be reduced in order for them to keep running for 25 years. Consider the suncream analogy: the PV backsheet is the 'suncream' for a module – its quality therefore determines the module's ability to fight against UV and exposure.

Since most modules will be located in an outdoor environment, it is well known that UV, moisture, high or low temperatures, chemical gases, sand particles and various other external conditions will affect them. This is the reason why these conditions all feature in the tests of module components and materials. As a module's outer protection, a backsheet needs to be versatile in terms of its function.

Burke says: "In order to protect modules for 25 years, backsheets need to possess three key characteristics: weather resistance, mechanical strength and adhesion strength. At the same time, these three characteristics must be optimally balanced."

David Li explains: "Of the three key characteristics, weather resistance mainly consists of UV proofing, and the resistance to hydrolysis, high/low temperatures (temperature difference between day and night) and sand abrasion. These resistance properties could support a module's suitability for use in different geographic and climatic environments around the world. For example, in desert areas, which are sandy and hot, good backsheets could endure the physical abrasion from sand and other external sharp objects; in some fire-prone areas, fluoropolymer film-based backsheets could prevent fires and reduce safety concerns."

Mr. Wu, a technical consultant at Krempelm, adds: "Good backsheets should protect cells from the surrounding environment, thus ensuring a high efficiency, and providing everlasting insulation protection."

Good-quality backsheets provide not only protection but also insulation: they prevent water vapour getting inside modules. Water penetration accelerates the degradation of ethylene-vinyl acetate (EVA) and the corrosion of conductive materials, thus impacting on cell efficiencies, lowering module power and even causing electricity leakage in the long term. All of these things could affect the power output of a module, as well as being potential hazards. Further studies have shown that a higher water vapour transmission rate in backsheets could lead to the acceleration of potential-induced degradation (PID).

Knowing the backsheet: material is the key

The quality of a backsheet is determined by its key material and by the structure of the materials used in it. DuPont categorizes backsheets into three basic types – double fluoropolymer, single fluoropolymer and non-fluoropolymer – and also defines many sub-categories within them. For the sake of simplicity, the market follows the two general categories of fluoropolymer and non-fluoropolymer.

> "The quality of a backsheet is determined by its key material and by the structure of the materials used in it."

David Li from Honeywell notes: "As a result of the severe squeezing of costs in recent years, backsheet companies have become very ambiguous about the fine line between fluoropolymer and non-fluoropolymer, because if a product contains some fluorine plastic, it could be deemed as fluoropolymer from a certain point of view. Nowadays, some backsheet coatings are claimed to be fluoropolymer, but the specific amount of fluoropolymer content is not known."

After considering all the information available, PV Tech observes the following categorization:

- First category: traditional fluoropolymer film-based compound backsheet (such as TPT, TPE, KPK, KPE, single-side THV).
- Second category: PET-like non-fluoropolymer backsheet.
- Third category: fluoride-coated backsheet.

Of these three types, the first is already in production and being used in the industry, which means it is more reliable and traditional; suppliers in this category include DuPont, Taiflex, 3M, Arkema, Honeywell, Toyo Aluminium, and Cybrid from China. It is noteworthy that DuPont and Arkema do not manufacture backsheets, but only the essential materials used in them: DuPont has its branded fluoropolymer products – Tedlar PVF film – and Arkema supplies Kynar PVDF film. Honeywell and 3M, however, are involved in the entire fluoropolymer supply chain. More details can be found in Table 1.

Why fluoropolymer films?

"Because good-quality fluoropolymer films resist ageing from external UV, backsheets made from these materials are not affected very much by UV, and the products have better resistance to the weather," explains David Li. "Whether a backsheet will last for 25 years depends on the molecular structure of its key materials. A fluoropolymer is made through high-temperature melting, after which high polymers form a complete film that is not easy to damage."

Regarding non-fluoropolymer PET – or polyester – backsheets in the second category, whose usage has been increasing in recent years, Li says the early products had a guaranteed lifetime of only 10–15 years – and that was just for rooftop use, where conditions are not so harsh. "Later, PET material manufacturers made some improvements, such as adding in some anti-UV reagents in order to delay the harm by UV rays to some extent; however, that process could not change the nature of polyester materials. Nowadays, Japan has extended its requirement for module lifetime to 20 years, leading to many Japanese module manufacturers changing their choices for backsheets."

It has been reported that non-fluoropolymer PET backsheets yellow after ageing by UV light and are prone to the risk of delaminating cracks. However, the manufacturing companies in the second backsheet category – such as Toray from Japan and Coveme – have different ideas. They believe that PET backsheets benefit from a low cost and are easy to process, while offering high adhesion between the layers and therefore having few problems with appearance.

There is only one issue on which compound backsheets suppliers and PET non-fluoropolymer backsheets suppliers agree – a problem which concerns fluoropolymer-coated backsheets: current backsheets coated with fluorocarbon ethyl vinyl ether (FEVE) are formed by chemical cross-linking, resulting in a relatively sharp mechanical form and poor wear-resistance properties, which makes them unsuitable for plants in west China, where there are strong winds and large amounts of sand.

FEVE-coated materials form a layer with a lower mechanical strength on the PET surface; thermal expansion and contraction may cause plastic materials to crack, and in certain areas where there are huge temperature differences and high humidity, backsheets easily become detached. In spite of that, PV newcomer Fuji Film has introduced a new backsheet product. One of the company's executive officers, Yoshihisa Goto, says its new backsheet enhanced by a glue-free coating employs two patent technologies which the company has used in camera films: one is enhanced PET-based film-manufacture technology, and the other is glue-free-coating precision-moulding technology. Goto also says: "The new backsheets use enhanced PET (hydrolysis resistant) at the backsheet interface instead of adhesive. These PET materials are UL certified for long-term usage under high temperatures (RTI values at 130°C), and are 250μm thick." Compared with traditional compound TPE backsheets, Fuji believes that, even after accelerated ageing tests, its backsheet products have the benefits of still maintaining the same power efficiency, the same water vapour transmission rate, the same breakdown voltage, and the same high weather resistance and safety levels.

Jiangsu Serphim Energy has employed Fuji Film's new backsheets. Peng Jin, CTO of Serphim, says the company tested many different backsheets last year and finally chose Fuji's material for the modules it later sold to Europe; the megawatt amount has now reached double digits.

As for fluoropolymer backsheets, their development and success have a close relationship with the whole market. In previous years, when the PV market was flourishing because of strong demand for PV backsheets in China, fluoropolymer films, especially DuPont's Tedlar PVF films, were in short supply. In response, companies came up with solutions for backsheets that do not use fluoropolymer films, but instead use fluoropolymer coatings on PET films; such backsheets have not only made it easier for companies who want to dabble in the backsheet industry, but also resulted in lower prices. At the time of writing, Jolywood and UM Technologies were the main suppliers of fluoropolymer-coated backsheets.

Backsheet type	Material structure	Company	Role	Price
I. Fluoropolymer film-based compound backsheets	*Double-side fluoropolymer* ①TPT Tedlar PVF/PET/Tedlar PVF ②Double-side PVDF PVDF/PET/PVDF (KPK) *Single-side fluoropolymer* ①TPE Tedlar PVF/PET/Tie Layer ②Single-side PVDF PVDF/PET/Tie Layer (KPE) ③Single-side ECTFE ECTFE/PET/Tie Layer ④Single-side THV THV/PET/EVA ……	DuPont	Fluoropolymer films supplier; the only supplier of Tedlar PVF, bought by Tailflex (Tailflex Solmate), SFC and Kempel for their compound backsheets. (T stands for DuPont Tedlar; DuPont states that only the backsheets using DuPont Tedlar PVF are truly TPT and TPE backsheets.)	High, with a 5–10% fluctuation range within the category Products from different suppliers have different characteristics
		Arkema	Fluoropolymer films supplier, providing Kynar PVDF fluoropolymer films; the K in KPK stands for Arkema Kynar PVDF.	
		Honeywell	The entire production chain of fluoropolymer films (Honeywell PowerShield ECTFE fluoropolymer films, backsheets).	
		Toyo Al	Backsheet supplier – procures the PVDF.	
		3M	Fluoropolymer films and backsheets (THV), currently selling a few non-fluoropolymer backsheets.	
		Krempel	Backsheet supplier – procures films from Arkema and DuPont.	
		Isovoltaic	Began with fluoropolymer backsheets, and has now turned to other materials.	
		Cybrid	Backsheet supplier – recently supplied KPF backsheets, with fluoropolymer films purchased from Arkema and SKC (Cybrid states that it could choose multi-materials, including PVF); sells a few PET backsheets.	
		Lucky Films	Backsheet supplier – procures fluoropolymer films.	
II. PET/partial PET non-fluoropolymer backsheets	PET polyester backsheets PET/PET/Tie Layer HPET Hydrolysis-resistant polyester HPET/HPET/Tie Layer	Coveme	Backsheet supplier – procures PET.	Medium, with fluctuation
		Toray	Material supplier, providing PET and backsheets.	
III. Coating-base and other backsheets	Coating/PET/Coating (Jolywood and UM use FEVE; LG uses PVDF) Coating/PET/Tie layer (Fujifilm)	Jolywood	Backsheet supplier.	Low
		UM	Backsheet supplier (HFF).	
		Fujifilm	Backsheet supplier.	Medium
		LG	Backsheet supplier.	Low
	PA/PA/PA nylon structure and other new materials	Isovoltaic	Backsheet supplier.	Low

Table 1. Backsheet types and some of the main material suppliers (the backsheet quality varies).

Which standards and tests are the most sensible?

Although there is some debate about which types of backsheet perform best, the distinction between them is becoming blurred. Each category has its suppliers and their supporters, who are trying to convince their customers to have confidence in and employ their products. Since there is currently no unified standard or recognized testing, all backsheet products could find their own breeding ground.

In relation to actual outdoor conditions, backsheet products need to be tested with respect to six aspects: UV light, temperature, humidity, environmental corrosion, electrical insulation and physical protection. It is believed that the current international standards are several years behind, failing to keep up with backsheet requirements. The tests for backsheets are normally done along with module testing, and the current criterion is IEC 61730, during which only the partial discharge property is tested.

To highlight the property advantages of a particular brand, there are numerous other tests on the market. "There are tests from certifying organizations, but the testing methods are not unified and overly promote a single performance indicator; new products are being introduced all the time, but only one or two of them have proven long-term outdoor usage experience. Currently, Krempel leads the march of progress in standardizing IEC backsheet criteria," Mr. Wu from Krempel tells *Photovoltaics International.*

"Some emerging companies have underlined the advantages of their products by performing tests that are several times more punishing than those in IEC testing," says Dr. Fu Bo, R&D director at DuPont (China). "However, the point is whether these tests are sensible. Some tests are called 'accelerated ageing tests' and are carried out under the conditions of PCT60-90hr (121°C/100%/2atm); a temperature of 121°C, however, is not appropriate for testing outdoor ageing – it should instead be considered to be 'destructive testing'.

"The purpose of testing is not to damage the products under extreme unusual conditions, but rather to expose them to close-to-outdoor conditions and simulated actual application environments, which is in accordance with the testing requirements of accelerated ageing conditions, but is lacking from current certification processes. The current certification tests for backsheets overstate the hydrothermal ageing tests but understate the UV ageing tests. There is no need to perform so many hours of hydrothermal ageing tests."

> "The current certification tests for backsheets overstate the hydrothermal ageing tests but understate the UV ageing tests."

Dr. Fu identifies a number of tests that would be useful for backsheets, one of which is a long-term UV ageing test. "In order to achieve 25 years' lifetime, backsheets need to undergo 275kWh/m^2 UV exposure for a desert environment, or 171kWh/m^2 for a milder climate. This test could single out those materials that are unable to resist UV ageing, and could reveal the potential risks of yellowing and cracks," he says.

A second regime would be a comprehensive ageing test, in which backsheet materials are tested against UV, temperature, humidity and multi-stress ageing in environments that resemble actual outdoor conditions. A third would be a sequence ageing test – for this a backsheet is subjected to thermal cycles after UV exposure. "This method could better simulate the impact of temperature differences between day and night, as well as between seasons, after the effects of outdoor ageing have taken their toll," says Dr. Fu. His final proposal is a test for conditions such as sand abrasion and chemical corrosion in environments characteristic of, for example, seashores, livestock sheds and industrial cities.

The current IEC certification tests do not include a UV ageing test or a weather-resistance test: the UV light intensity used in the IEC certification tests only equates to 70 days' outdoor exposure, and there is no requirement for such tests for the back side of a module. To solve this problem as soon as possible, many material suppliers, such as Krempel and DuPont, are discussing the need for a revision of the IEC standards for backsheets. Revising standards, however, takes time, and during the period of revision it is entirely up to the individual companies whether or not they act in accordance.

Costs determined by the technical roadmap

Since no single standard exists and there are lots of confusing tests, the market in PV backsheet production is increasingly being overrun by local companies. With production being localized, competition has flourished in recent years and, along with international top-tier material suppliers, many domestic backsheets companies are emerging.

Every backsheet company makes its own choices of materials and product structures; the market has therefore been flooded with a multitude of backsheet products. The immediate result of this has been a turbulent market and chaotic pricing. It is known that the price battle between backsheet companies is extremely fierce, with prices ranging from RMB10/m^2 to RMB30/m^2 (approximately US\$1.64–4.92/m^2). On top of that, there is a tremendous variation in quality. Although the market in backsheets has been broken into, the actual essential materials are not something every company is capable of possessing because of large technical obstacles, and consequently these materials are mostly controlled by international suppliers.

Costs are determined by the technical roadmap, and therefore prices will vary. The first category, fluoropolymer backsheets, has the highest prices: 10 to 15% higher than PET backsheets, and the prices vary within the category. As for fluoropolymer-coated backsheets, the prices of some of the new types are relatively low. Within the three categories there are different price groups, and hence pricing gaps: the difference in costs is therefore magnified. Under pressure to reduce costs, manufacturers have brought down the price of fluoropolymer backsheets over the last few years. Some manufacturers have reduced the thickness of the

Conditions	Times	Testing Items	Measuring Units	Testing Standards	Results (red)	Results (orange)	Results (green)
Outer Layer UVA	>3000h	Yellowing (Junction Box Side)	Δb*	ASTM E308	≥2	<2	<1
	>3000h	Elongation	% Loss	ASTM D882	≥80%	<80%	<50%
Outer Layer UV - Xenon	5000h	Inner Layer Stability	n/a	Visual	Cracked	Slightly Cracked	Good
Damp Heat	1000h	EVA Adhesion	% Loss	ASTM D903 (180 deg) ASTM D1876 (t-peel)	≥50% or Break	<50%	<20% or Glass Peel
	1000h	Elongation	% Loss	ASTM D882	≥80%	<80%	<50%
Thermal Exposure	Varies	Inner Layer Softening Temp.	°C	JIS K7196	n/a	<170	>170
Initial	0h	Coefficient of Thermal Expansion (MD, TD)	(μm/C*m)	Internal	≥100 (MD or TD)	<100 (MD or TD)	<50 (MD or TD)
Outdoor Performance	Varies	Years Used in PV Backsheet*	Years	n/a	<20	n/a	≥20

TEST/PROPERTY DETAIL

Damp Heat: 85°C, 85% RH.
UVA: 70°C, QUV 340 nm, 1.2 W/m²-nm at 340 nm, continuous.
Xenon: ASTM G155 cycle 7A (modified), Xenon .55 W/ m²-nm at 340 nm, daylight filter, 65 BPT, continuous, no water spray.
CTE: -40°C tp 85°C.
*For non-TPT™ backsheets, numbers shown are based on commercial introduction from Photon 2011 Survey.

Figure 2. Testing and valuation standards for PV backsheets suggested by DuPont.

fluoropolymer films in response to price declines; if the reduction is beyond a reasonable range, however, it could have a huge impact on backsheet quality.

"I do not agree in cutting costs by cutting back on the amount of material used in products. Nowadays, the whole industry remains competitive through reducing, and just as with 'white goods' the trend is a vicious cycle," says Mr. Wu from Cybrid. Costs should be cut by technology innovation, he believes, highlighting Cybrid's newly developed Flursoskin technology, an upgrade of the KPE products.

Mr. Wu goes on to say that KPE products were developed and patented by Cybrid in 2010, and first used by Trina Solar and later by other backsheet companies. During their use, however, problems emerged, including poor UV resistance, which prevented the KPE film from playing its protective role in addition to other roles of the product in the long term.

In the area of domestic backsheet production, along with Cybrid and HIUV, another company – Jiangsu Gorichen New Materials – has begun to manufacture backsheets; its FPE backsheet film has passed CPVT (National Centre of Supervision and Inspection on Solar Photovoltaic Products Quality) tests. It is said that Gorichen's backsheet oriented itself as a fluorine-based compound backsheet, employing PVDF materials from KUREHA, whose PVDF materials have a proven track record of almost 30 years as a fluorine weather-resistant layer in certain applications.

According to Lux Research, the current demand for materials used in crystalline silicon modules is the largest market opportunity, with US$23.8bn expected to be reached by 2018. Backsheets, non-EVA laminations, metallization coatings and anti-reflection coatings for module glasses are the specific areas having innovation initiatives and being key to product quality. It is this market opportunity that is attracting ever more material suppliers, such as the entry of Fuji Film into the solar industry. Newcomers will further agitate this specific niche of the market, and downstream module manufacturers and plant operators will need to pay particular attention to it.

Backsheet usage by companies

The diversification of backsheets has a direct impact on the downstream industry: module companies can now choose from many different backsheet suppliers.

According to research published in *Photovoltaics International*, most mainstream module manufacturers – including Yingli, CSUN, Canadian Solar, JA Solar, Suntech, Renesola, Tianwei, HT-SAAE and Sunowe – currently choose compound backsheets, whose market share was 68% in 2011–2012, followed by PET backsheets with 20%. Fluoropolymer-coated backsheets accounted for 7%, with the remainder at 5%.

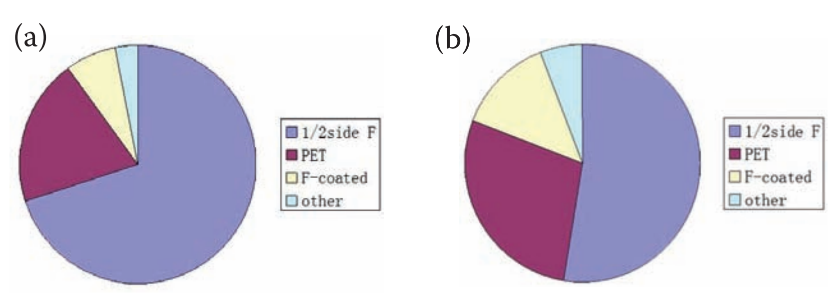

Figure 3. Market share trends for different backsheets: (a) 2011; (b) 2012.

As indicated by data, the market share of PET backsheets rose significantly in 2012 because of the influence of the market and pricing. Other large companies – including Trina Solar, Hareon Solar and Talesun – have turned to PET non-fluoropolymer backsheets for some of their products and also to the fluoropolymer-coated backsheets: as a consequence, the market share of compound backsheets has declined (see Fig. 3). According to feedback from module manufacturers, the type of backsheet they choose relates, to some extent, to the market they are supplying. Moreover, backsheets in the different categories demonstrate different results in the various certification tests, and sometimes a certain property is the key criterion for a specific market.

Another crucial factor affecting the change in market share is price. In recent years a vicious cycle of buying has become apparent among Chinese module manufacturers because of the pressure to rapidly cut costs. They probe into the materials used by their competitors and compare prices with fellow companies; this information is then used as the rationale for buying materials. As mentioned above, the three categories of backsheet have three price ladders; in particular, compound backsheets are much more expensive than those in the other two categories, so it is not difficult to understand why backsheets of poorer quality and thus higher risk might be used.

Conclusions: precautionary action

If the condition of backsheets and other key components and materials is taken into account, it is expected that within a few years, there could be an explosion of issues with modules as they present with the kinds of problem outlined at the beginning of this paper. Parts of China, for example Qinghai, are considered high risk areas for backsheets because of the strong UV light, dry air and huge temperature differences, all of which could be fatal to backsheets, which might begin to suffer from cracking.

Many plant operators are beginning to pay serious attention to the problem. Some of the major power companies in China, for example, have specified that Tedlar PVF TPT backsheets be used by module suppliers for deployment in western China. Despite the high price per square metre, backsheets that are able to endure an outdoor usage of 25 years will, in the longer term, have an ROI that is still higher than that achievable with other backsheets.

But the rest of the industry needs to remember that PV plants are long-term capital projects, requiring huge investment and a long ROI period. PV manufacturers should not, for the sake of a better bidding price, cut corners and carelessly rush out key components of the plant. How long PV plants made of such components will last could have a direct impact on the development of the entire PV industry.

> "When problems are reported, it is already too late – for a plant designed to run for 25 years, precautionary action is far more important."

In the case of the PID phenomenon, no one cared about it until reports of problems in plants emerged and brought the issue into the spotlight. But when problems are reported, it is already too late – for a plant designed to run for 25 years, precautionary action is far more important.