Traditional designs are comprised of three key film components – Air Side, Inner Core, and Cell Side – with many product options (Table 1). A variety of fluorinated films such as Tedlar (PVF), Kynar (PVDF) and Halar (ETCFE) to name few are now available without these as alternate product variants with differing value propositions. Also, polyethylene-terephthalate (PET) film based PPE backsheets have been adopted by the global PV module manufacturing community. Beyond multi-layer backsheets described above, co-extruded backsheets are also gaining popularity minimizing interfacial adhesion and separation concerns associated with laminated products. Yet the latest and likely lowest cost backsheets entering into the bill of materials are based on coating technology wherein both the Air and Cell side materials are replaced by a durable fluorinated coatings designated such as CPC or FPF product types wherein letters C and F represent a thin fluoro-polymer coating layer. Thus in conclusion, many backsheet types are available and can be confusing as to which one to qualify while balancing targeted physical properties, reliability and cost variables.

<table>
<thead>
<tr>
<th>Backsheet Design</th>
<th>TPT</th>
<th>KPK</th>
<th>TPE</th>
<th>KPE</th>
<th>PPE</th>
<th>KPC</th>
<th>CPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Side Film</td>
<td>PVF</td>
<td>PVF</td>
<td>PVF</td>
<td>PVF</td>
<td>PET</td>
<td>PVDF</td>
<td>Coating</td>
</tr>
<tr>
<td>Inner Core Film</td>
<td>PET</td>
<td>PET</td>
<td>PET</td>
<td>PET</td>
<td>PET</td>
<td>PET</td>
<td>PET</td>
</tr>
<tr>
<td>Cell Side Film</td>
<td>PVF</td>
<td>PVDF</td>
<td>Olefin</td>
<td>Olefin</td>
<td>Olefin</td>
<td>Coating</td>
<td>Coating</td>
</tr>
</tbody>
</table>

Purpose of this tutorial is to summarize key backsheet design components to assist process, quality and procurement engineers in selecting most suitable backsheet for their PV application. More specifically, each key film component – Air Side, Inner Core, Cell Side - in backsheet design with respective functionalities and potential concerns will be reviewed.
Air Side Film Technologies

Just like front glass sheet, polymeric backsheet films also contribute to environmental protection of the photovoltaic cells, metallization, solder joints, etc. and thus should be viewed as an important and integral part of the finished PV module. In order to select a backsheet, design engineers need to develop a more detailed understanding of each functional layer within a backsheet in addition to conducting industry standard certification and qualification tests. Not all backsheet designs perform comparably and equally well.

From the Table 1, a number of different Air Side material options are available as highlighted before. Key functions and requirements for the Air Side film of the backsheet includes:

- Intrinsic Weathering Stability - UV and moisture resistance
- Resistance to abrasion (sand, airborne particulates)
- Resistance to tear, crack or physical deformation
- Thermally stable above processing and use temperature
- Electrical insulation
- Protection of the inner core PET film

Due to decades of demonstrated outdoor and UV-stability in non-solar applications, fluorinated polymer films, respective adaptation to solar market is not surprising. In fact, Tedlar, Kynar and Halar films have become the de facto materials of choice for the outer layer of the backsheet due to exceptional UV-light and outdoor stability and will likely retain such position.

Tedlar shortages steered market to explore and adapt to new backsheet constructions such as all PET backsheet abbreviated as PPE. Coveme has aggressively and successfully marketed such products globally. As the air side of the construction, typically pigmented, UV and hydrolysis stabilized PET film is required to meet the rigors of environmental stability while protecting Inner Core film. Various field reports presented in different solar reliability conferences suggest that PPE backsheet experience structural breakdown in outdoor use. However, without understanding product design details, selection of materials, process robustness, one cannot generalize that PET based products are inferior to other designs. In other words, product design details matter. However, it has been reported that fluorinated polymer films outperform UV and hydrolysis stabilized PET films in tests where UV-exposure durations exceeds PV industry standard test requirement.

Backsheets based on low cost CPC format have thin, likely pigmented fluorinated coating on both side of an Inner Core PET. Such products may be more prone to weathering degradation as summarized under the E-layer section below.

Inner Core Insulation Films

A part from co-extruded films, as the inner core film, all other backsheet designs use hydrolytically stabilized PET film of various thicknesses depending upon end use application such as 1000 V or more recently 1500V systems. Inner core PET film serves a number of key functions including electrical insulation, mechanical stability, vapor barrier and must be hydrolytically stabilized. Hydrolytic stability is measured by Pressure Cooker test (PCT) conducted at 121 oC/100% RH/2 atm using time as a variable. It is suggested that PCT rating at least of 48 hours is required for a stable inner core PET layer. Again, if either Air Side or Cell Side films fail due to weathering or mechanically, degradation of the core insulation film commences marginalizing various functions of the backsheet itself leading to premature loss of PV module power output.

Cell Side Films and Coatings

Cell or EVA side backsheet surfaces commonly referred to as “E-layer” also plays a critical role in the long term reliability of the PV module. Primary functions of the E-layer include:

- Inner core PET film protection
- Thermal stability against deformation and softening
- UV-stable, non-yellowing
- Electrical insulation
- Adhesion to core film and encapsulant such as EVA
- High reflectance
- Heat dissipation

Just like the Air Side of the backsheet construction, E-layer can represent a number of material options. While fluorinated polymer films promote exceptional UV-stability, perhaps the most accepted, lower cost alternative is an olefin based adhesive layer designated by letter E in TPE, KPE and PPE designs. New contenders to E-layer technology are based on thin coating technologies typically fluorinated materials. A number of such products have entered into the marketplace by Coveme, Hangzhou First, Cybrid Technologies and others.

E-Layer reliability

Typical E-layer is made of a low melting adhesives such as polyethylene (mp.120 oC) or ethylene vinyl acetate (mp.90 oC) both thermoplastic materials thus deforming and softening during heat exposure. This is problematic in two fronts; during vacuum lamination and use life in high temperature installations. During the vacuum lamination process typically conducted at 140-160 oC under vacuum, E-layer melts pushing ribbon wires towards and in direct contact with inner core PET layer thus reducing electrical insulation characteristics of the backsheet due to changes in DTI. In addition, these olefin based layers may yellow under UV-exposure and have been reported to crack, pulverize and disintegrate exposing Inner Core films to a damaging UV-light thus marginalizing the safety and reliability of the PV module itself. Figure 2 compares UV-light exposure of four different products namely KPE, PPE, KPC and PPC type designs in that order from left to right.
Table 2: Long Term UV-Stability of E-Layer and related Materials

Yellowing index was monitored as a function of time at the onset and after 150KWhrs on both sides of the backsheet. On the back side, color change was within specifications while cell side E-layer yellowed considerably. Two products representing KPC and PPC representing UV-stabilized primer layer retained specifications. Physical deterioration of the E-layer took place between 150 and 300 KWhr of UV light exposure while coating type adhesive layer remained undamaged.

<table>
<thead>
<tr>
<th>Color change</th>
<th>Spec.</th>
<th>A-company 1</th>
<th>A-company 2</th>
<th>Cynagard 225A (KPF)</th>
<th>Cynagard 275A (PPF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR side</td>
<td></td>
<td>0 KWh 150 KWh 0 KWh 150 KWh 0 KWh 150 KWh 0 KWh 150 KWh 0 KWh 150 KWh</td>
<td>0.8 3.2 0.8 3 0.5 0.4 0.9 3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVA side</td>
<td></td>
<td>150KWH A-company 1</td>
<td>A-company 2</td>
<td>Cynagard 225A (KPF)</td>
<td>Cynagard 275A (PPF)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.7 8 0.5 7.7</td>
<td>1 0.8 1.8 0</td>
<td>-0.2 -1.8</td>
<td></td>
</tr>
</tbody>
</table>

Observations

This relatively short narrative covered a number of common backsheet products in the marketplace addressing key performance features and relevant concerns.

While certain backsheet designs and laminate components are well known by the industry such as Tedlar, Kynar and Halar with an impeccable performance history, yet new innovative products have entered into this competitive marketplace balancing price to performance ratio for applications from utility scale to domestic roof-top applications. Intent of this review is not to rate one backsheet technology against the other but to increase the awareness of backsheet design and how each layer contributes to the key properties and ultimately the long term weathering stability and reliability of the PV module in delivering bankable performance and power output. In conclusion, PV industry is shifting from dual layer fluorinated film constructions (TPT, KPK, others) to lower cost designs comprising E-layer. The very latest products are based on E-layer replacement designs like PPC and KPC type laminates combining the best worlds of UV-stable, chemical resistant, low flammability rating and high abrasion resistant PVDF or other fluoro-polymer films with equally well performing fluorinated coating on the cell side thus contributing to the extended use life the advanced PV module designs.