The Material of Choice for Photovoltaic Encapsulant Films

ENGAGE™ PV Polyolefin Elastomers
The Power of ENGAGE™ PV POEs for Photovoltaic Encapsulant Films

As photovoltaic module manufacturers and end-users continue their efforts to reduce overall cost/watt/area and improve long-term reliability, the use of highly efficient and cost-effective components becomes even more essential. While encapsulant materials are used primarily to protect and preserve the photovoltaic cell, the choice of encapsulant material can have a major impact on module power output, reliability, service life, and total system costs.

ENGAGE™ PV Polyolefin Elastomers (POEs) allow PV encapsulant film and module manufacturers to develop films that help reduce module and system lifetime costs by significantly:

- **Increasing power generation** with greater electrical efficiency, reliability, and life expectancy
- **Improving resistance to potential induced degradation (PID), and lowering the potential for premature module failure and replacement**

ENGAGE™ PV POEs are used to produce top and back encapsulant films designed to protect the photovoltaic cell in PV modules (Figure 1). These differentiated materials from The Dow Chemical Company (Dow) are ideally suited for rigid modules that use crystalline silicon (c-Si) or thin film technologies, and can also be used in flexible module configurations and concentrated photovoltaics (CPV). Advanced encapsulant films based on ENGAGE™ PV POEs are used by leading module manufacturers across the globe for large- and small-scale residential, commercial, and utility installations.

![Crystalline Silicon Photovoltaic Module Using ENGAGE™ PV Polyolefin Elastomers](image)

**Figure 1:** Crystalline Silicon Photovoltaic Module Using ENGAGE™ PV Polyolefin Elastomers
Increased Power Generation

Field testing of full modules demonstrates the ability of ENGAGE™ PV POE-based encapsulant films to provide increased power output due to reduced power degradation over time. A study conducted at Florida Solar Energy Center showed that modules using ethylene vinyl acetate (EVA)-based films lost more than three times more total power output during the three-year test period than those using films based on ENGAGE™ PV POEs. From a quantitative perspective, the results may vary depending on cell, module construction, and environmental conditions. Qualitatively, however, the effect of lower power degradation on increased power output is accepted based on inherent differences between ENGAGE™ PV POE- and EVA-based encapsulant films. The enhanced power output over time translates into a significant advantage in total energy generation over the lifetime of modules and systems made using ENGAGE™ PV POE-based films versus those using EVA-based films.

To help illustrate this advantage, the total power degradation rate for each material has been calculated and listed in Table 1. Power degradation rates are conservatively estimated at 0.35 percent per year for ENGAGE™ PV POE-based encapsulant film and 0.7 percent per year for EVA-based film (i.e., a 2X higher power degradation rate for EVA-based film vs. the >3X higher rate cited in the Florida Solar Energy Center study). Modules made with EVA film also typically lose an additional 1.7 percent power per year (again, conservatively) due to PID, while modules using ENGAGE™ PV POE-based film typically experience virtually no PID. Finally, the degradation rate and PID are combined to determine the total power degradation rate. Figure 2 conceptually shows the impact of lower total power degradation and increased total energy output over the service life of the module and system.

In this example, the advantage of a 2.05 percent higher power output rate per year results in a total projected energy increase of 24 percent over a 25 year period for modules made using ENGAGE™ PV POE-based encapsulant films compared to modules using EVA-based films. The reduction in power degradation is so significant it could potentially extend the service life of modules made with ENGAGE™ PV POE-based films to 30 years.

Table 1: Estimated Power Degradation Rates of Modules Using Selected PV Encapsulant Films(1)

<table>
<thead>
<tr>
<th></th>
<th>Power Degradation (% loss / year)</th>
<th>Potential Induced Degradation (% loss / year)</th>
<th>Total Power Degradation (% loss / year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVA-based Film</td>
<td>0.7</td>
<td>1.7</td>
<td>2.4</td>
</tr>
<tr>
<td>ENGAGE™ PV POE-based Film</td>
<td>0.35</td>
<td>0.0</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Figure 2: Projected Power Output of Modules Using Selected PV Encapsulant Films Over 25 Years(1)

(1) Data per tests conducted by Dow. Additional information available upon request. Properties shown are typical, not to be construed as specifications. Users should confirm results by their own tests.

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Advantaged Materials Deliver Advantaged Performance

Table 2 compares the typical characteristics of PV encapsulant films made with ENGAGE™ PV Polyolefin Elastomers and EVA. As you can see, the ENGAGE™ PV POE-based film offers comparable or improved performance in all key areas.

**Enhanced Electrical Properties**

As shown in Tables 2 and 3, the volume resistivity levels of encapsulant films made with ENGAGE™ PV resins are very high compared to those made with EVA, adding to the ability to insulate the module and maintain cell reliability. Higher volume resistivity allows the module to best conduct the electrical current and helps enhance and maintain consistent module efficiency levels over time, while also helping resist PID. Dow testing shows that ENGAGE™ PV POE-based encapsulant film has volume resistivity two orders of magnitude higher than EVA-based film. (1)

The significantly higher volume resistivity of ENGAGE™ PV POE-based encapsulant film translates to leakage current levels that are up to two orders of magnitude lower than EVA-based film (Tables 2 and 3). (1) Maintaining low leakage current helps enhance electrical insulation performance, reduce the effects of PID, and further improve module reliability and service life.

Figure 3 shows that the leakage current of modules using EVA-based encapsulant film is also much more sensitive to increasing temperatures, which can negatively impact module reliability levels. Reliability can be further compromised by the tendency of EVA-based film to experience large increases in leakage current when exposed to increasing humidity levels. Neither of these issues is a concern for ENGAGE™ PV POE-based encapsulant film, which maintains consistently low leakage current throughout the test.

Additionally, the dielectric strength of ENGAGE™ PV POE-based encapsulant film is significantly higher than EVA-based film (Table 2). Higher dielectric strength offers the potential to operate modules made using ENGAGE™ PV POE-based film at higher voltages.

**Increased Protection from Moisture**

Solar cells can be damaged by exposure to moisture or water, causing significant efficiency losses and potential failure. The use of encapsulant film made with ENGAGE™ PV POEs helps PV modules resist moisture.

**Table 2: Typical Characteristics of Selected PV Encapsulant Films**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>ENGAGE™ PV POE-based Film</th>
<th>EVA-based Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume Resistivity, ohm-cm @ 23°C (73.4°F)</td>
<td>≥2.64E+16</td>
<td>1.32E+14</td>
</tr>
<tr>
<td>Leakage Current, picoamp @ 23°C (73.4°F)</td>
<td>19</td>
<td>3,795</td>
</tr>
<tr>
<td>Dielectric Strength, kW/cm</td>
<td>601</td>
<td>444</td>
</tr>
<tr>
<td>Water Vapor Transmission Rate (WVTR), g/m²-day @ 38°C (100°F)</td>
<td>3.3</td>
<td>34</td>
</tr>
<tr>
<td>Thermal Conductivity, W/m-K</td>
<td>0.291</td>
<td>0.246</td>
</tr>
<tr>
<td>Optical Transmission, %</td>
<td>&gt;92%</td>
<td>93</td>
</tr>
<tr>
<td>Refractive Index</td>
<td>1.475</td>
<td>1.455</td>
</tr>
<tr>
<td>Glass Transition Temperature (Tg), °C (°F)</td>
<td>-45 (-49)</td>
<td>-35 (-31)</td>
</tr>
</tbody>
</table>

(1) Data per tests conducted by Dow. Additional information available upon request. Properties shown are typical, not to be construed as specifications. Users should confirm results by their own tests.

(2) Dow Method. Additional information available upon request.

(3) Encapsulant film thickness was 457 microns for all specimens. All WVTR units are in g/m²-day@38°C (100°F).

(4) Average value from 450-1050 nm, total hemispherical light transmission, 18 mil film.

(5) Based on testing conducted by Florida Solar Energy Center. Additional information available upon request.
The higher thermal conductivity of encapsulant films made with ENGAGE™ PV resins also reduces module operating temperatures, allowing for increased module efficiencies in high-temperature environments. Improved module efficiency enables immediate cost/watt reductions and provides the potential for significantly lower LCOE across an extended service life and warranty period.

**Excellent Optical Performance**

Strong optical properties are essential to optimizing the power output of PV modules. As shown in Table 2 (page 4), ENGAGE™ PV POE-based encapsulant film offers excellent optical transmission with rates comparable to those of EVA-based film. In addition, the refractive index of film made with ENGAGE™ PV POEs is very close to that of glass, reducing refractive losses off of the glass-polymer interface and maximizing light transmission to the active cell material. Combined with high volume resistivity levels, this performance has a very positive effect on overall power generation and preservation.

**Other Key Benefits**

The chemical composition of ENGAGE™ PV POEs gives them a very stable backbone, providing module manufacturers with ease of processing and the potential for considerably reduced conversion costs. In addition, ENGAGE™ PV POEs contain no liquids that can cause hydrolysis or lead to bubble formation, thus eliminating the formation of acetic acid that could damage lamination equipment and modules.

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**Table 3: Electrical Property Comparison of Selected PV Encapsulant Films**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature Tested, °C (°F)</th>
<th>Electrical Properties</th>
<th>Volume Resistivity (ohm-cm)</th>
<th>Leakage Current (picoamp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGAGE™ PV POE-based Encapsulant Film</td>
<td>23 (73.4)</td>
<td>≥2.64E+16</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40 (104)</td>
<td>9.47E+15</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60 (140)</td>
<td>4.12E+15</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td>EVA-based Encapsulant Film</td>
<td>23 (73.4)</td>
<td>1.32E+14</td>
<td>3,795</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40 (104)</td>
<td>2.48E+13</td>
<td>20,244</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60 (140)</td>
<td>6.45E+12</td>
<td>77,636</td>
<td></td>
</tr>
</tbody>
</table>

(1) Data per tests conducted by Dow. Additional information available upon request. Properties shown are typical, not to be construed as specifications. Users should confirm results by their own tests.

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ENGAGE™ PV POE-based Films Enable More Power, Longer

Virtually No PID

Solar cells under high voltage stress can degrade significantly within a short amount of time. The resistance of the encapsulant material to potential induced degradation (PID) can make a major difference during field usage, with higher levels of PID resistance resulting in sustained levels of module efficiency. Testing shows that power degradation in modules using EVA-based encapsulant films is far more likely and will occur much more rapidly than in modules using film made with ENGAGE™ PV POEs.

Detailed PID tests conducted in 2013 by the Fraunhofer Center for Silicon Photovoltaics CSP compared modules using ENGAGE™ PV POE-based encapsulant film to modules using EVA-based film. Three modules using ENGAGE™ PV POE-based film and six modules using EVA-based film were exposed to three test cycles, with each cycle exposing the module to 50% RH and -1000 V at 50°C over two days. A recovery period of ten days at room temperature in a dark room followed the first exposure cycle. Test results showed that all modules using ENGAGE™ PV POE-based encapsulant film did not exhibit PID in any cells, while all modules using EVA-based film experienced PID, even following the recovery period. Additionally, all modules containing EVA-based film showed a significant number of cells with PID by the third cycle run. Current-Voltage (IV) curves show that modules using EVA-based film exhibited significant and rapid power loss.

In the test, one of the six modules that used EVA-based encapsulant film experienced PID across all cells even before the recovery period. Representative findings of this test are shown in Figure 4. These PID test results would correspond to significant power loss – or failure – in the field for the modules using EVA-based film.

Enhanced Power Retention

The ability of modules to withstand extended exposure to damp heat can significantly extend service life. Damp heat testing has demonstrated that a module made using ENGAGE™ PV POE-based encapsulant film can retain its initial efficiency level for a much longer period than a module using EVA-based film (Figure 5, page 7). Long-term weathering tests show that modules using encapsulant film made with ENGAGE™ PV resins can provide enhanced power retention following alternating cycles of damp heat and QUV exposure over extended periods (Figure 6, page 7). Additionally, the photos in Figure 7 (page 7) illustrate that modules featuring ENGAGE™ PV POE-based encapsulant film exhibit excellent color stability and help resist yellowing after extended damp heat testing, while those with EVA-based film show yellowing and increased degradation levels.

After the third test cycle run, a module using ENGAGE™ PV POE-based encapsulant film showed no PID, while a module using EVA-based film exhibited PID across a number of cells and experienced rapid loss of power output.

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(1) Tests conducted by the Fraunhofer Center for Silicon Photovoltaics CSP. Photographs and charts provided by Fraunhofer. Additional information available upon request.

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**Figure 5: Extended Module Reliability – Damp Heat**

Following 1,000 h Damp Heat, both modules underwent 50 Thermal Cycles and 10 Humidity Freeze Cycles. Both modules were then placed back into Damp Heat.

- Module made with ENGAGE™ PV POE-based Encapsulant Film
- Module made with EVA-based Encapsulant Film

**Figure 6: Long-term Module Weathering**

ENGAGE™ PV POE-based Encapsulant Film

EVA-based Encapsulant Film

**Figure 7: Color Stability After 5,500 Hours of Damp Heat Testing**

ENGAGE™ PV POE-based Encapsulant Film Maintains Excellent Stability

EVA-based Encapsulant Film Shows Degradation

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Dow has quickly become the supplier of choice for leading PV encapsulant film and module producers – and we continue to grow.

ENGAGE™ PV Polyolefin Elastomers used in crystalline silicon PV modules are listed as “Recognized Components” by Underwriters Laboratories (UL). Additionally, panels made with ENGAGE™ PV POE-based encapsulant films have been performance tested by TÜV Rheinland in Germany. Following requirements of IEC 61215, the panels were shown to perform well in all test protocols.

**An Ongoing Investment in Innovation**

For decades, Dow has been an industry leader in polyolefin resin and film technology. The family of ENGAGE™ Polyolefin Elastomers is based on Dow’s proprietary polyolefin catalyst, resin, and film technologies. Dow is the world’s leading supplier of polyolefin elastomers, having pioneered their development in the 1990s and now providing well over 1.5 billion lbs. to the electrical, automotive, infrastructure, and consumer markets. Production facilities for ENGAGE™ POEs are located in all the major regions of the world including North America, Europe, the Middle East, and Asia. A development team dedicated to polyolefin innovation for photovoltaic films has continued to expand our product capabilities and customer support across all regions. This team is constantly working to further enhance the performance and processing of these differentiated materials.

For more information, contact your Dow representative, visit www.dowpv.com, or call the nearest location on the following page.
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