# DEVELOPMENT OF WEATHERING TESTS, TOWARDS MORE RELIABLE PV MATERIALS AND COMPONENTS

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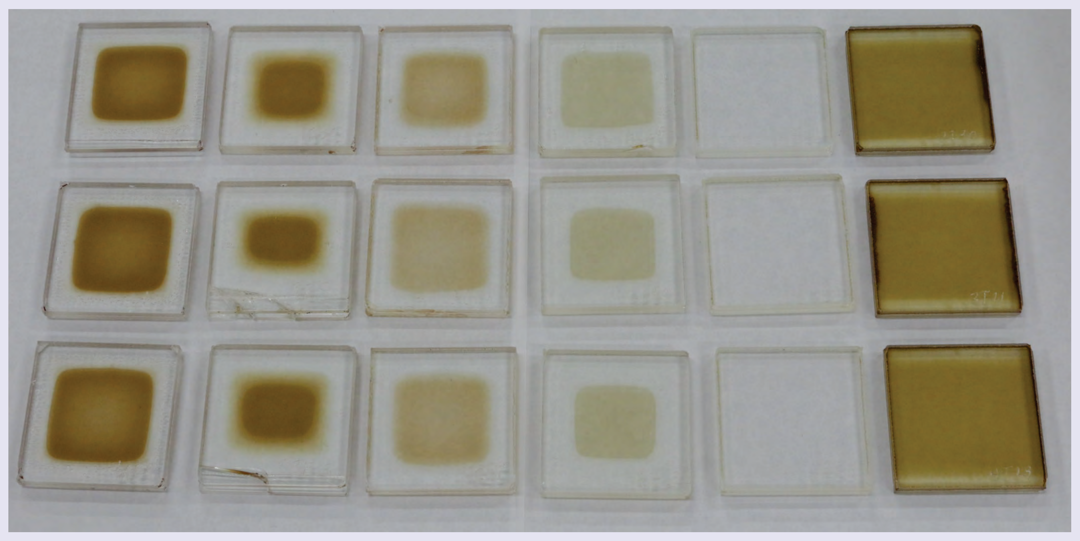
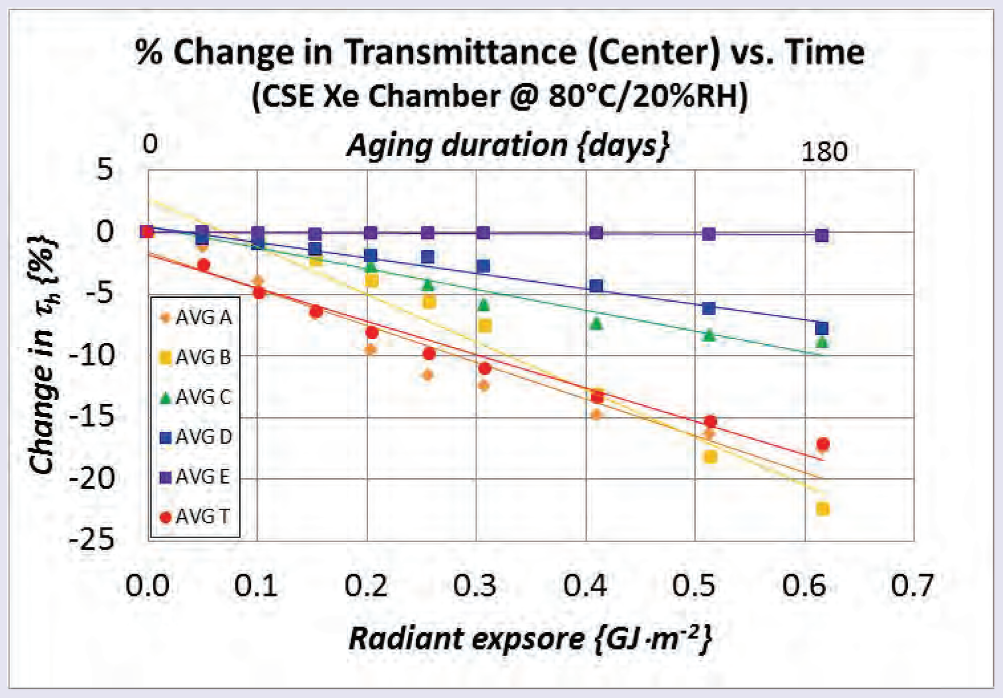
***Previous research***, as an example, has examined the reduction in transmittance of encapsulants from UV weathering. For example, Task Group 5 within the PV Quality Assurance Task Force (PVQAT) has organized an interlaboratory study at 14 institutions regarding the UV aging of encapsulants. Similarly, 12 institutions are collaborating on a weathering experiment for backsheets, in support of the IEC 62788-7-2 standard. These studies: examined PV materials using non-specific weathering and characterization equipment (serialized examination); worked towards specific purposes (monotonic weathering); and had limited applicability (examining beyond the Safety and Design Type Qualification tests, but only a few year's field use). References: (TG5 $\tau$ study) http://www.nrel.gov/docs/fy15osti/63508.pdf and http://www.nrel.gov/docs/fy15osti/64628.pdf

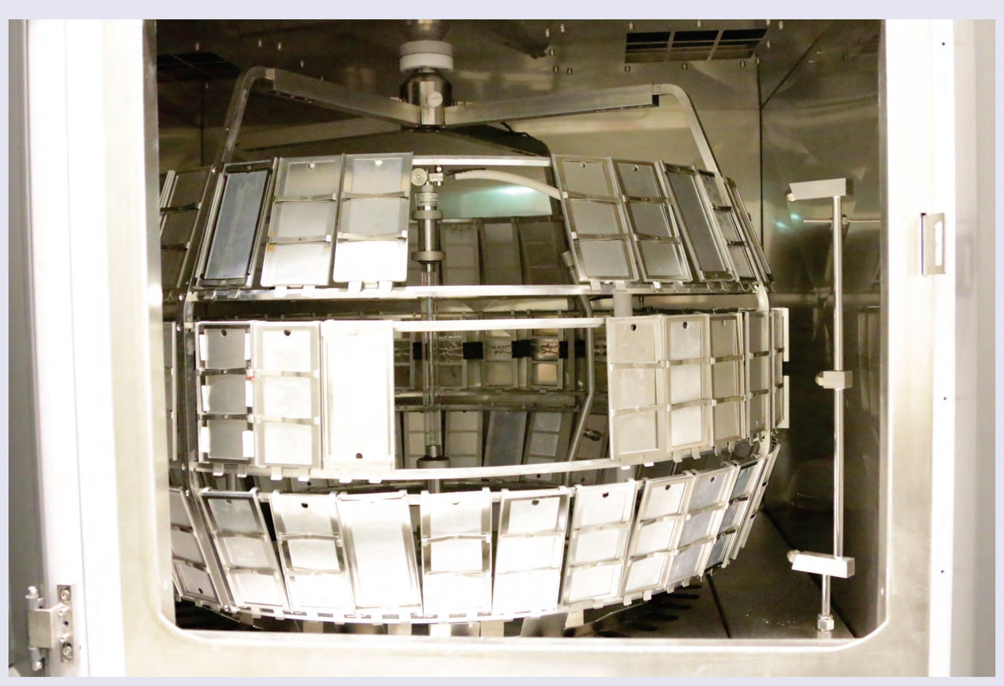


*LEFT: Photograph of representative encapsulation specimens at the end of the TG5 study. A set of (18) 50 mm x 50 mm silica/encapsulant/silica coupons was used (for 6 materials) in each sub-experiment.*

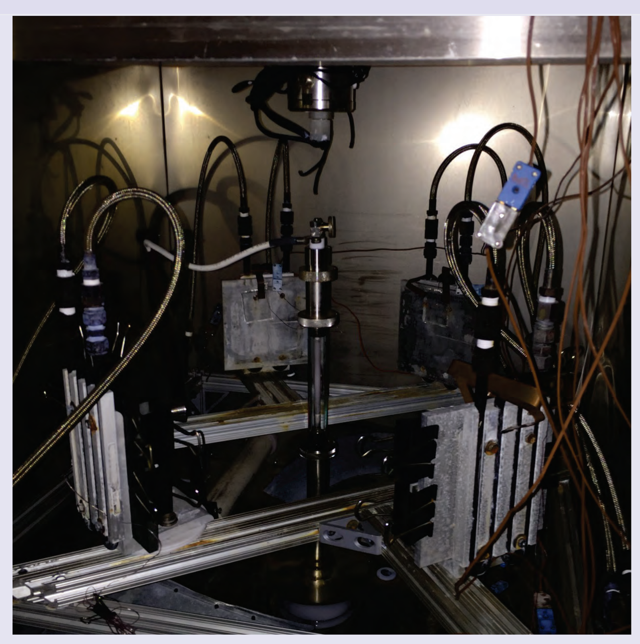



*RIGHT: Measured change in hemispherical transmittance for the same test specimens. The measured data is compared to a linear (sometimes with limited applicability) to guide the eye.*

***Test specimens*** may include any materials or components used in a PV module. Historically, much study has been devoted to encapsulants. Future work could examine: backsheets; metallization pastes; ribbon interconnects; junction boxes (typically containing several components); connectors; adhesives; and/or antireflective/antisoiling coatings. It could be argued, for example, that composite backsheets are inherently more complex than monolithic encapsulants. Further, any of the packaging materials may be subject to complex interactions with the other materials and components present in a module. Interactions between the packaging components is not often addressed in the PV research literature.



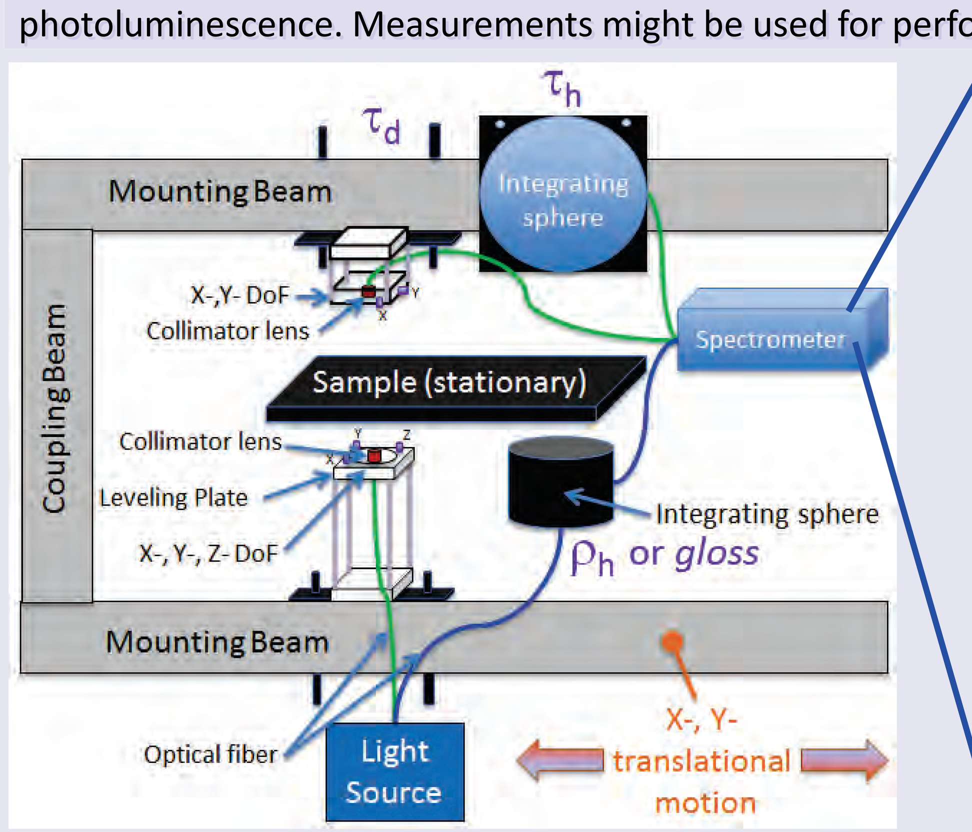
*LEFT: Many specimens can be weathered in parallel in a Ci5000 Weather-ometer, using a Xe lamp, which best replicates the UV spectrum of the sun, as described in ASTM D7869.*



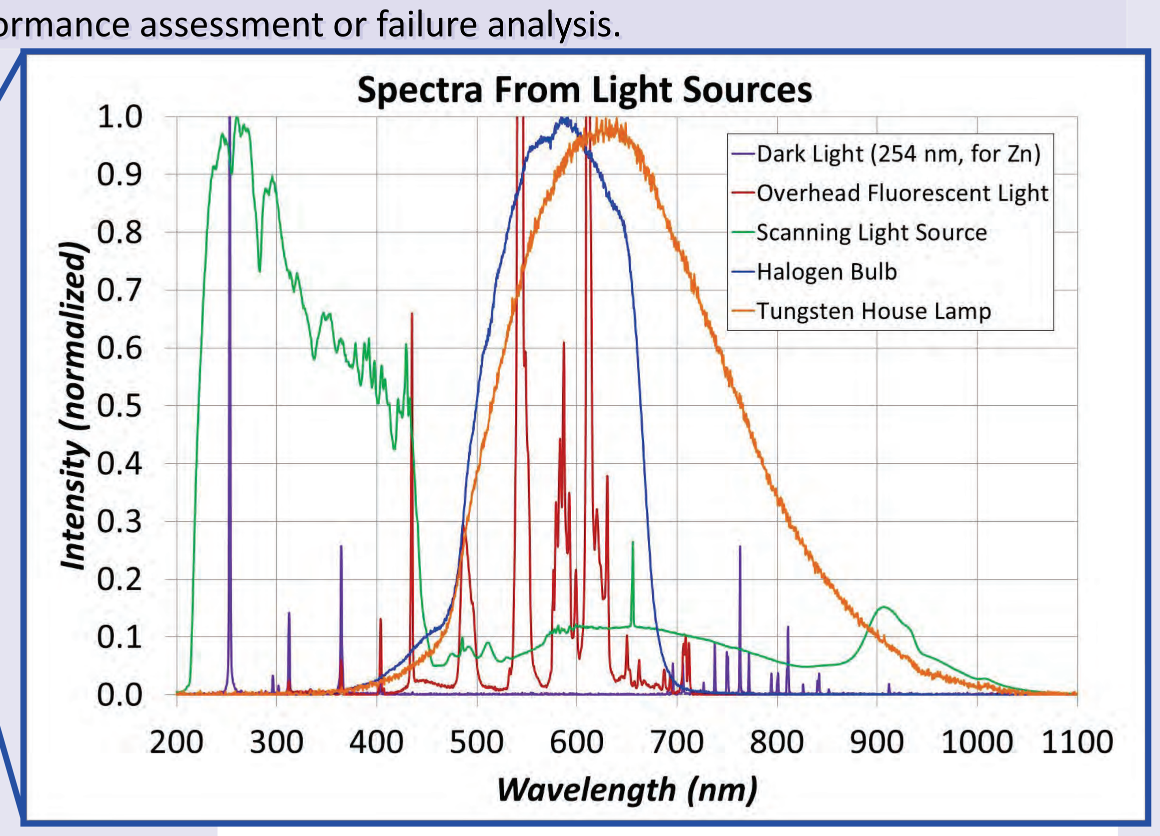
*RIGHT: A NREL customized Ci4000 can independently control the irradiance and temperature at the specimen plane. The chamber could be used to expedite the determination of activation energy and/or reciprocity effect (non-linearity with irradiance intensity).*

***Automated weathering*** may be achieved, even applying UV, temperature, and humidity at once. Equipment capability unique to NREL includes multiple Xenon-lamp Weather-ometer chambers (including a chamber customized for high irradiance aging). The chambers have the capacity to examine many specimens in parallel (for a common applied weathering regiment). These chambers have proven useful for determining key weathering parameters like activation energy. NREL also has a custom chamber that could be used to examine activation energy for a smaller sample set. Recent work has focused on steady state weathering. NREL also has the capability to weather module-sized specimens in an Atlas XR260 Xenon chamber. Future work might apply conditions in an aging cycle (to better cover diurnal variation or most severe circumstances) and/or a sequence of different weathering tests, like used in module qualification.

***Automated measurement*** may be used to expedite materials reliability research. Parameters like optical transmittance could be more rapidly measured in a custom instrument (rather than a spectrophotometer), with the specimens handled in a cartridge carrier. Regarding failure analysis, Raman spectroscopy could likewise be performed using a cartridge carrier to allow stepping between specimens or mapping within specimens to analyze their degradation. A scanning stage allowing module size range of travel could easily be adopted for DuraMat to measure: transmittance (hemispherical or direct), reflectance (hemispherical, *i.e.*, with an integrating sphere), gloss, Raman shift, Fourier transform infrared spectra, electroluminescence, or photoluminescence. Measurements might be used for performance assessment or failure analysis.

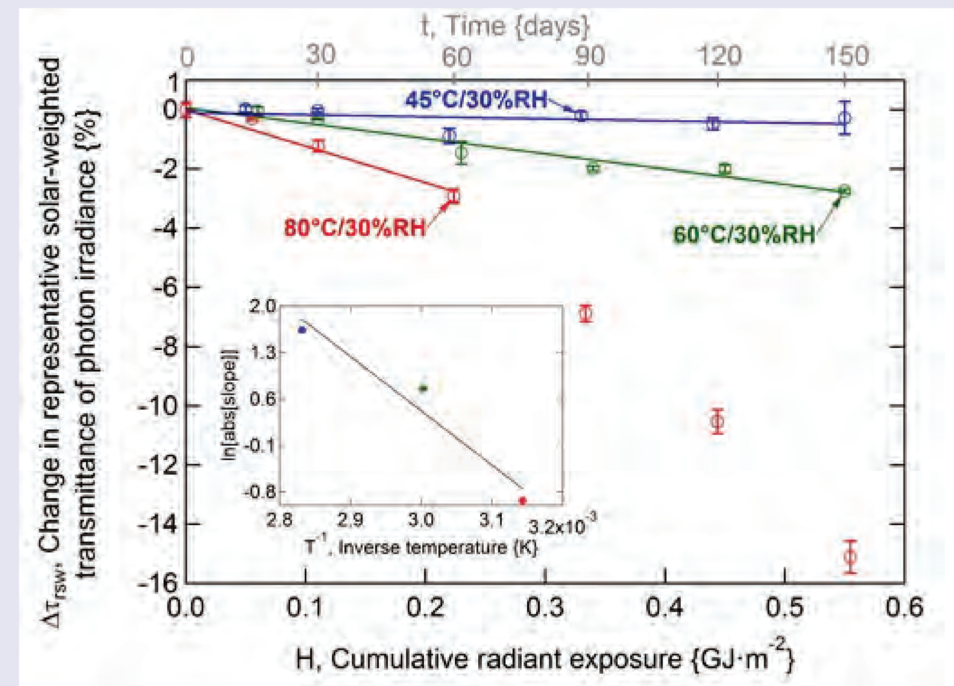



*LEFT: Schematic of proposed optical scanning capability, including transmittance (hemispherical and direct), reflectance (hemispherical), and gloss.*

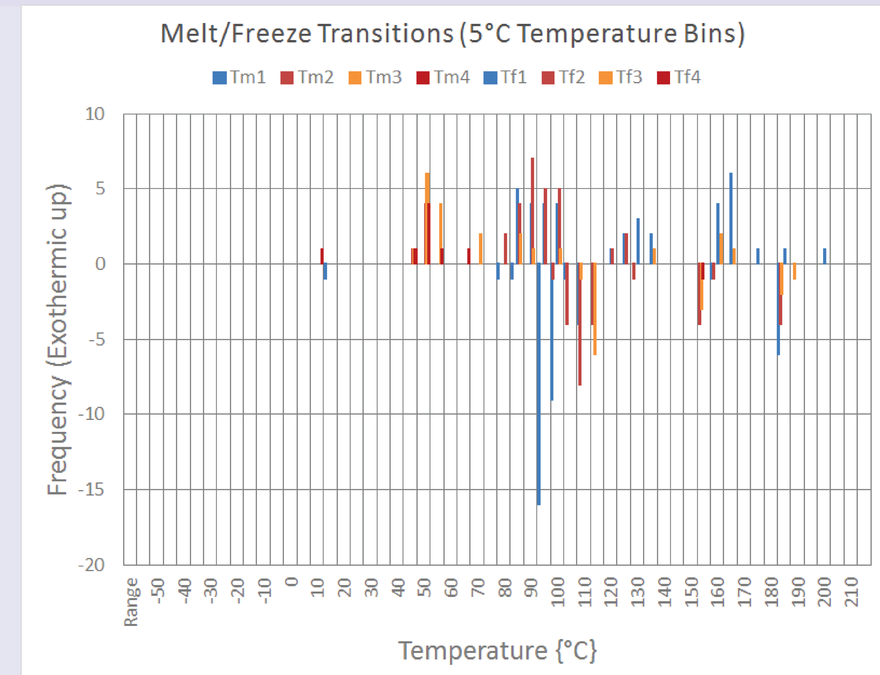



*RIGHT: Representative spectra from various light sources obtained using the spectrometer. The data has been scaled and then normalized to better distinguish the spectra.*

***Topics of study*** might include: the kinetics (activation energy) of degradation; the dominant weathering factors; and the material specific action spectrum. Activation energy can importantly vary outside a typical operating temperature range or material phase state. Within the limitations of those constraints, activation energy may used for service life estimation. The magnitude and interdependence of weathering factors could be quantified in a Design Of Experiments (DOE) study (no previous literature examples for PV materials reliability). The action spectrum (for UV weathering) identifies the susceptibility of damage as a function of wavelength, which can be used to distinguish between materials, design to protect materials, or verify the use of a proper irradiance source.

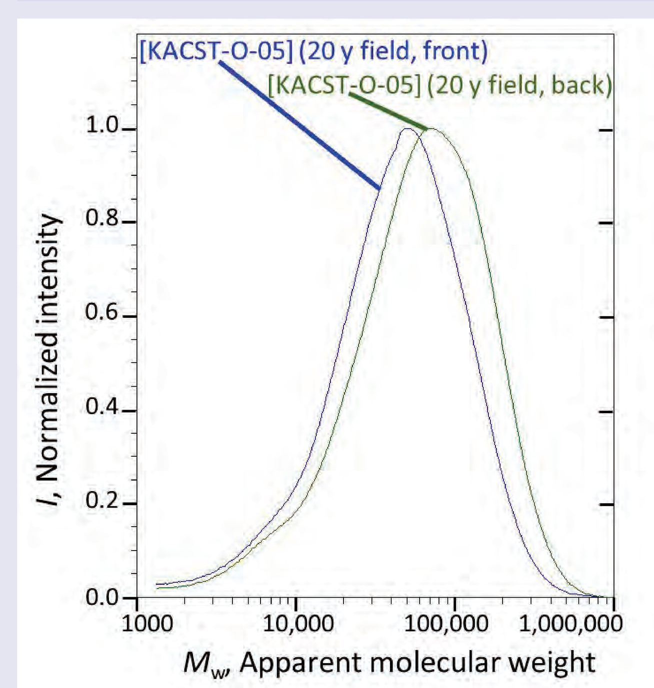



*LEFT: Activation energy can be estimated from valid performance degradation data, e.g., where initial formulation additives have not been completely depleted. The example here is shown from the TG5 encapsulaton study for a benchmark EVA formulation.*

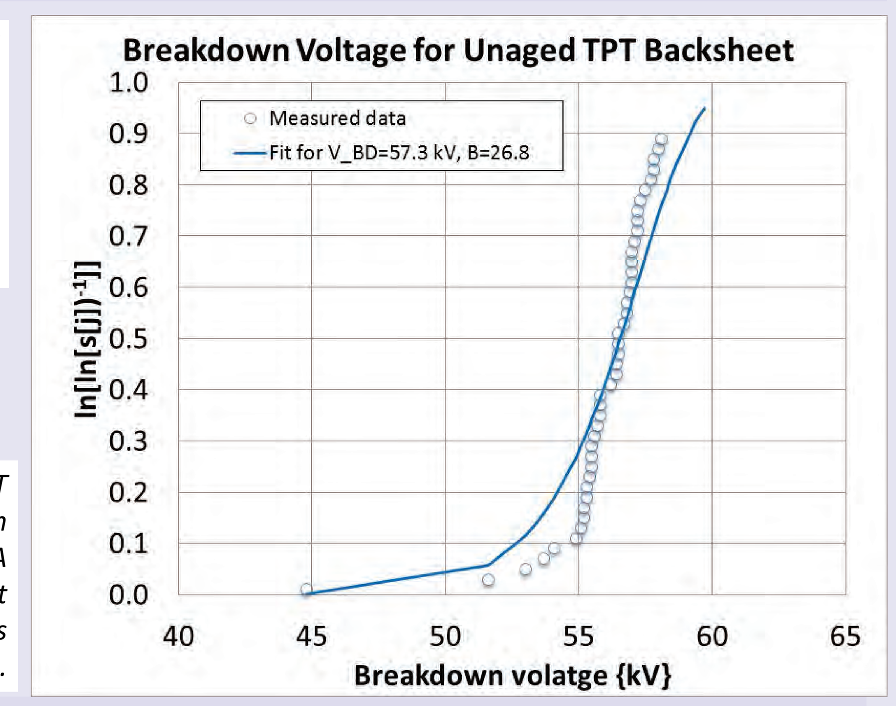



*RIGHT: Phase transition can affect the degradation kinetics, limiting the applicable range for the measured activation energy. The example here shows the population of melt/freeze transitions for a variety of commercial backsheet products examined in the interlaboratory experiment for the IEC 62788-7-2 UV Weathering standard.*

***Failure analysis*** of PV packaging materials & components has been often overlooked or minimally examined in past research, which will become important for emerging materials with no PV legacy. NREL has a suite of materials analysis capability, including resources in other research centers, e.g., biofuels. Example capabilities include: optical spectrometry; UV-VIS fluorescence spectrometry; mechanical testing (loadframes); dynamic mechanical analysis (DMA); differential scanning calorimetry (DSC); thermogravimetric analysis (TGA); gel permeation chromatography (GPC); gas chromatography-mass spectroscopy (GCMS); nuclear magnetic resonance (NMR, liquid & solid state); goniometry (contact angle); scanning electron microscopy (SEM); energy dispersive x-ray spectroscopy (EDS); Auger electron microscopy (AES); x-ray photoelectron spectroscopy (XPS); transmission electron microscopy (TEM); focused ion beam (FIB); Fourier transform infrared spectroscopy (FTIR); Raman spectroscopy; atomic force microscopy (AFM); white light interferometry; and spectroscopic ellipsometry .




*LEFT: GPC was used to verify that UV degradation was occurring on the surface of veteran CPV lenses. The loss in performance of the lenses was found to suffer more from abrasion. Reference: Miller et. al. Proc. 11th Intl. Conf. CPV , 2015.*




*RIGHT: The breakdown voltage for TPT backsheet well exceeds the maximum of 1.5 kV for utility installations. A reduction in material thickness might be warranted, if the material proves robust with age.*

***Application of research*** could include: safety (e.g., IEC 61730 standard) and design type qualification (e.g., IEC 61215); more accurate understanding/analysis of component lifetimes; more accurate understanding of what is required for the application. All of these considerations affect the type, number, and amount of material(s) used, readily affecting the cost of PV technology. For example, the DOE SETO is presently suggesting the use of 50 year product life for PV to reduce cost and provision for energy storage device(s). Like the automotive and other industries, the industry is working towards a series of material and component standards, i.e., the IEC 62788 series .

***Validation of results*** including the results of outdoor experiments is critical to accelerated weathering tests. Spurious degradation modes can dominate artificial tests when highly activated kinetic processes (high activation energy) outcompete less active processes at elevated temperatures, masking the results. NREL also has experience examining veteran modules, including the inspection of large (MW sized) PV installations. The advent of veteran or decommissioned installations now allows the industry the opportunity to study the component materials to determine what is truly required for the application and avoid costly overdesign.

*LEFT: NREL has outdoor rack capacity, including accelerated (concentrator) fixtures, and has worked with partners in the weathering benchmark locations of Phoenix and Miami .*

*RIGHT: NREL has performed site inspections, including at APS, SMUD, and TEP utility installations. Reference: Wohlgemuth et. al., Proc IEEE PVSC 2015. DOI:10.1109/PVSC.2015.7356132*

***Acknowledgements***

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***Disclaimer***


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