BAPVC Annual Project Report

Project Title: PV Module performance & Lifetime Prediction: Inserting New Technologies Without Lifetime Penalty

PI: Roger H. French, Kenneth D. Singer, Jiayang Sun, Guo-Qiang (GQ) Zhang

E-mail: rogerfrench@case.edu

Summary: A data science approach is being developed for the performance and lifetime prediction (PLP) tool from modules in Cleveland, OH. Accelerated study protocols are being developed on materials and mini-modules that elucidate key degradation modes. The PLP tool is being developed using semi-supervised generalized structural equation modeling (semi-gSEM) for statistical analytics to understand degradation pathways and to rank order key degradation modes.

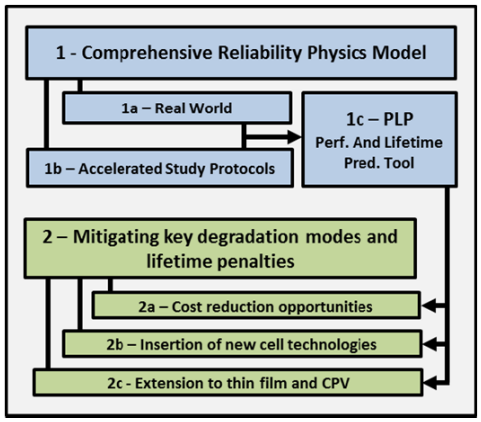

Figure 1: The CRPM consists of task 1a (real-world), 1b (ASP studies), and 1c (PLP tool) which is then utilized in tasks 2 a, b, and c.

Key Accomplishments: The comprehensive reliability physics model (1) proposed for BAPVC utilizes both real-world data from modules for time series analysis (1a) and accelerated study data for materials, components, mini-modules and modules (1b) to elucidate key degradation mechanisms. The insights from real-world and accelerated exposures are investigated using statistical analytics based on chemistry and physics using semi-gSEM to develop the PLP tool (1c) (Figure 1).

TSA (1a) was performed on modules on the SDLE SunFarm using a data science approach and statistical methodology such as hierarchal cluster analysis. New variables that give rise to power production difference not identified by module nameplate properties. The TSA research gave insights into statistically handling of seasonal variations as well as correlating power production with weather data to understand the exact conditions seen by the PV modules[1,2,3]. Collaborative work was initiated with HelioVolt for TSA of real-world exposed modules. Now the group is beginning to engage with SunPower for TSA of their real-world exposed modules.

Study protocols (1b) have been developed for many different materials of PV modules. Domain science and statistical analytics are being used to inform ASPs for the highest information content on degradation mechanisms[4,5].

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[1] Hu, Y., M.A. Hosain, T. Jain, Y.R. Gunapati, L. Elkin, G.Q. Zhang, R.H. French. "Global SunFarm Data Acquisition Network, Energy CRADLE, and Time Series Analysis." *IEEE Energytech*, 1–5, 2013.

[2] Hu, Y., Y. Xu, T.J. Peshek, J. Sun, R.H. French. "Data Science Approach to Time Series Analysis of Real-World PV modules" PV Module Reliability Workshop, Denver Co. 2014.

[3] Hou Y., Y.R. Gunapati, Y. Hu, P. Zhao, R.H. French, G.Q. Zhang. "Energy-CRADLE: An Hbase infrastructure for data-driven energy research." Case Engineers Week. 2014.

[4] Wheeler, N.R., L.S. Bruckman, J. Ma, E. Wang, C.K. Wang, I. Chou, J. Sun, and R.H. French. "Statistical and Domain Analytics for Informed Study Protocols." 1–7. IEEE EnergyTech, 2013.

[5] Wheeler, N.R., Y. Xu, A. Gok, I.V. Kidd, L.S. Bruckman, J. Sun, R.H. French. "Data science study protocols for investigating lifetime and degradation of PV technology systems." IEEE 40th PVSC Conference. Denver, Co., June 8-13 2014 (Submitted).

The PLP tool (1c) uses our semi-gSEM methodology to understand the relationships between stresses, degradation mechanisms, and overall performance loss and was applied to c-Si modules under accelerated conditions (damp heat and UV preconditioning). The semi-gSEM methodology was then applied to acrylic degradation of importance to CPV and MAPV type technologies, to understand degradation pathways in this material. The statistical pathway diagram shows that the added UV light stabilizers (iIAD2, iIAD2p) prevents the degradation by irradiance of the fundamental absorption edge (iIAD1) and thereby reduces the optical performance losses through yellowing (YI)[6] (Figure 2).

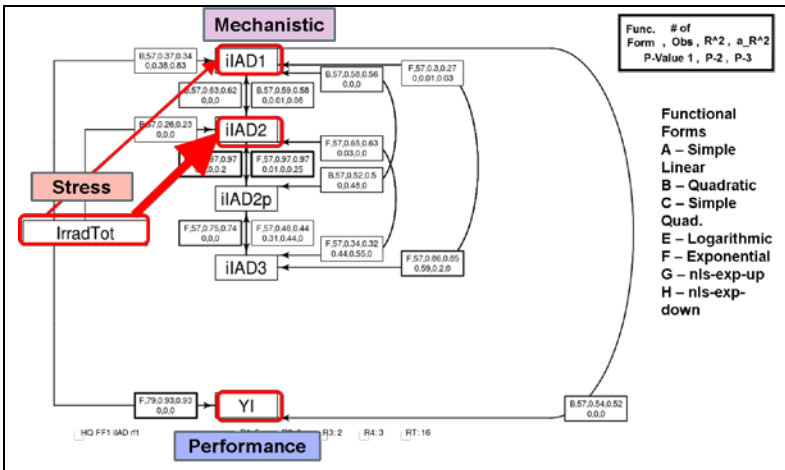

Figure 2: Statistical pathway diagram UV stabilized acrylic degradation in the irradiance only QUV exposure showing the UV stabilizers are degrading due to irradiance.

Key degradation modes can be mitigated (2) with the PLP tool by guiding cost reduction opportunities (2a), new technology insertion (2b) and apply the PLP tool to other technologies (2c) (Figure 1). Research on PV backsheets and PET suggests that hydrolytically stabilized PET may not be necessary because PET does not appear to hydrolyze in real-world conditions. Using nonstabilized PET could be a key way to reduce the cost of modules (2a). This work is in partnership with Dupont.

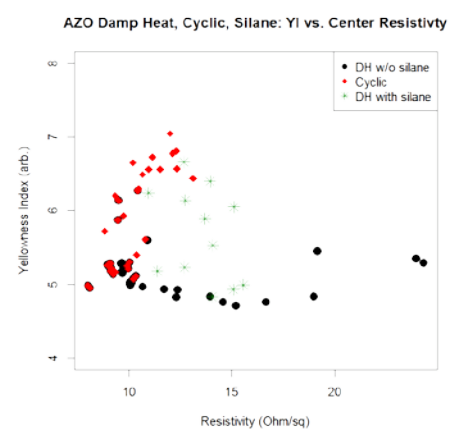

Figure 3: YI compared to Resistivity for AZO in open-faced cyclic, and damp heat, and silanized damp heat.

Current metallization techniques are being investigated in mini-modules in order to understand the front side silver and interconnect degradation. This information will be applied to novel metallization type techniques to help with new technology insertion (2b).

The PLP tool was initially applied to thin film technology (2c) with silane interfacial layers on TCOs. The silane is shown to increase the lifetime (decrease of resistivity) of these TCOs[7] (Figure 3). This is work is in partnership with Underwriter Labs.

Future Work: includes information extraction for the retained sample library. Refining of the semi-gSEM methodology will be conducted to include not only Markovain relationships between variables. The group is pursuing future research with Purdue and Georgia Institute of Technology members of BAPVC.

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[6] L.S. Bruckman, N.R. Wheeler, I.V. Kidd, J. Sun, R.H. French; "Photovoltaic lifetime and degradation science statistical pathway development: acrylic degradation". Proc. SPIE8825, 2013.

[7] Lemire, H.M., K.A. Peterson, S. Sprawls, K. Singer, I.T. Martin, R.H. French. "Degradation of transparent conductive oxides:mechanistic insights across configurations and exposures", Proc. SPIE 8825. 2013.