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NATIONAL RENEWABLE ENERGY LABORATORY

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NREL Efforts to Address Soiling on PV Modules

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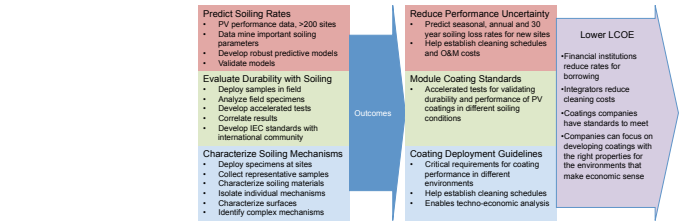
U.S. DEPARTMENT OF ENERGY
Office of Science

I. Introduction

Natural soiling has reduced the energy output of PV systems since the inception of the technology. Soiling is a complex problem that increases uncertainty and drives up LCOE through lost energy production, increased O&M costs, and higher finance rates. In NREL's comprehensive review of solar energy soiling,[1] the issues have been discussed in the literature for more than 70 years, and yet "the fundamental properties of dust and its effect on energy transfer are still not fully understood, nor is there a clear solution to the problem." For this project, NREL is performing systematic efforts to understand the processes involved so that the effects of soiling can be predicted for different environmental conditions and to provide the PV industry the tools/ knowledge necessary to devise cost effective mitigation.

II. Methodology and Goals



IV. Conclusions and Future Pursuits

Mechanisms:
- *Capillary and van der Waals forces scale with contact area, not particle size*
- *Developed working definition of cementation and demonstrated method that determines when loose dust particles become cemented*
- *Need to quantify additional adhesion mechanisms*
- *Need to identify appropriate cost effective cleaning/mitigation strategies*

Standards:
- *Characterizing long term soiling/corrosion processes of fielded PV modules*
- *Initial glass coupons deployed around the world*
  - *First year results starting to come in: organic materials major component*
- *Little damage from accelerated test brushes*
- *Dust slurry causing some haze*
- *Need to correlate accelerated test results to observed field observations*
- *Begin drafting standard(s)*

Soiling Rates:
- *Initial procedures to determine soiling losses from production data working*
- *Initial correlation between soiling losses & environmental factors identified*
- *Need to expand to many more sites to validate initial findings*

References

1. Sarver et. al., Renewable and Sustainable Energy Reviews, 2013, vol. 22, issue C, pages 698-733
2. "An Investigation of the Key Parameters for Predicting PV Soiling Losses", Micheli et al. Progress in PV, http://onlinelibrary.wiley.com/doi/10.1002/pip.2860/epdf.
3. "A Scalable Method for Extracting Soiling Rates from PV Production Data", Deceglie et. al., IEEE PVSC 2016

Acknowledgements

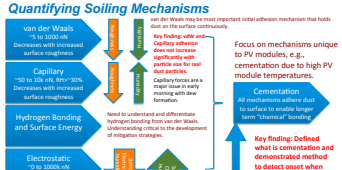
The authors would like to acknowledge and thank all those who contributed to this project including Sarah Kurtz, Alan Sellinger, our industry collaborators, and partners around the world. This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 to the National Renewable Energy Laboratory.
Collaborations: First Solar, SunPower, EDF, Sun Edison, Enki Technology, 3M, DSM, DEWA, KISR, QEERI, KACARE, Wells Fargo

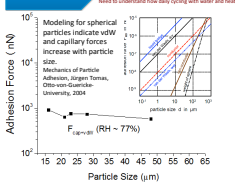
III. Results

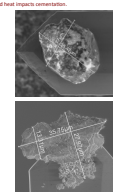
Outcomes

Coating Deployment Guidelines

Quantifying Soiling Mechanisms

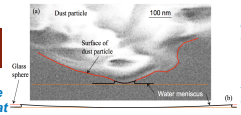




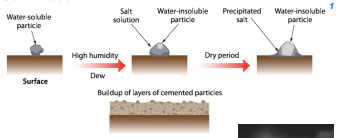


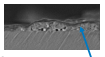
Contact area of real dust particles does not scale with particle size

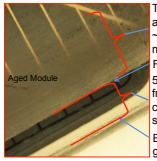
see Moutinho et.al., PVSC Proceedings 2017 [1]



Cementation





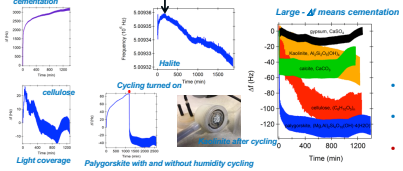


Tenacious deposits at frame edge ~ 1 cm at all module edges
Frame edge
5 mm glass w/ frame removed is clear and does not show soiling
Edge of module/ glass

Is this Cementation?

see Perkins et. al., PVSC Proceedings 2017.

Onset of cementation is detected with several materials on QCM SiO_2 surface w/ humidity cycling.



Cycling between humid and dry air causes the particles to initially age, as did the silica spheres. However, at some point, the fundamental interaction between the particles and QCM surface transitions to where it transmits "shear."
The formation of rigidly adhered particles marks the formation of cementation. As more particles become cemented the frequency continues to decrease. With cementation detected, we can now quantify the different processes involved. Created tool to test surfaces/coating that prevent cementation.

Module Coating Standards

Accelerated Testing

Accelerated testing results:
- *As expected brushes themselves do not damage the glass surface*
  - *Differences in transmittance measurements are within the measurement noise*
- *Haze values are small and within the noise*
  - *After 14,000 cycles with AZ slurry a haze is discernable to some eyes*
- *After 20K cycles, scratches using a slurry with larger dust particles are much higher than that observed on field glass.*

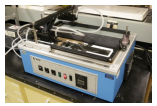


Image of scratches from accelerated test with wet slurry at 20 K cycles.

NREL abrasion tester running wet slurry test.

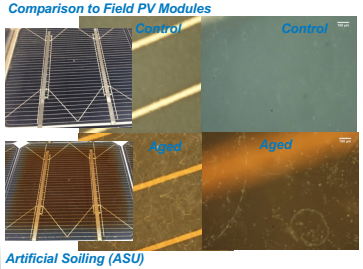
With wet dust slurry a slight haze begins to form after 20 K cycles.

Match observed degradation to accelerated test results.

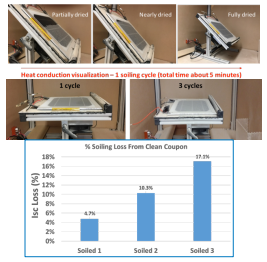
Long Term Outdoor Tests

Deployed:
Mumbai, IIT
Tempe, AZ
Sacramento, CA
DEWA, UAE
Kuwait
Brazil

Comparison to Field PV Modules



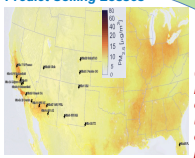
Artificial Soiling (ASU)



- *Inexpensive chamber and dust delivery components.*
- *Humidity and temperature controlled to mimic daily dew and heat cycles*
- *Chamber can deliver reproducible amount of dust (collected from outdoor PV panels) to produce a uniform layer with controlled thickness*
- *This type of system will be needed to perform accelerated tests associated with PV module coating durability and effectiveness.*

Reduce Performance Uncertainty

Predict Soiling Losses

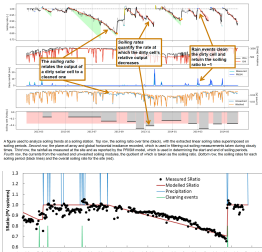


Create soiling loss map based on predictions using environmental parameters.

Correlate environmental parameters to soiling loss.
- *90% correlation to $PM_{2.5}$ and dry period length for initial 10 sites.*

see Micheli et. al., PVSC Proceedings 2016 and 2017 [2]

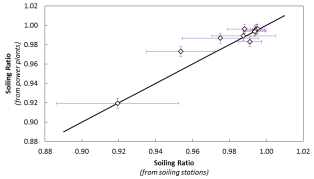
Obtain soiling loss from production data.



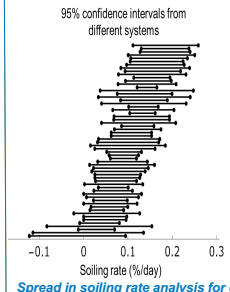
Soiling stations

Production data

Automatically extract soiling loss from PV system data.



Uncertainty in soiling station is large because more frequent cleaning is needed
- *Comparison with "soiling station" data at 10 initial sites indicates method is working. Expanding to more data sets.*
  - *Less than a 1% absolute difference at 8 sites*



Spread in soiling rate analysis for different sites.
- *see Deceglie et. al., PVSC Proceedings 2016 and 2017* [3]

Lower LCOE: O&M, Finance