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Heliostat Consortium for Concentrating Solar-Thermal Power

Transferring Photovoltaic lessons learned to Concentrating Solar Power

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conceptual design • components • integration • mass production • heliostat field

Outline

- Points worth noting in the history of the PV industry
- PV benefits from standardization
- PV sharing reliability challenges since the 1975
- PV projects from an independent engineering (IE) perspective
- Site selection (what NOT to do)
- PV Operations & Maintenance over time
- Soiling research (remove the silos)
- Noting a few relevant PV IEC standards
- PVfleets data sharing

PV History, Standards, and Reliability Work

Points worth noting in history of the PV industry

- 1960s-1970s: first PV production but mostly research and space applications due too extremely high cost
- 1975-85: JPL block V DOE/industry reliability work (this outdoor testing and failure analysis is a key turning point to the industry making improvements through standards testing while targeting long outdoor life
- 1981: IEC Technical Committee 82 formed
- 1986: SERI hosts first thin film PV reliability workshop; kickstarts shared PV reliability workshops that now occur annually
- 1990s-2000s: significant subsidies and tax incentives around the world enable the development of a terrestrial PV industry, driving further cost reduction ($5/Watt)
- 2010-2015: Industry moves to a commodity product as manufacturing rapidly shifts to Asia. This enables further rapid cost reduction below the price of fossil fuels ($1/Watt). (Many companies go bankrupt while others arise)
- 2015-present: the industry continues rapid growth and cost reduction with a strong focus on reliability (2022: 1 terawatt cumulative deployment achieved)

Why PV standards been so important

- Having products live for 30 years in the harsh outdoors is a challenge most products/engineers/designers don't have to face
  - High wind, hail, UV, extreme temperature swings, dust storms, and more
- JPL work set the trend for:
  - An intelligent approach understanding/handling such challenges
  - Establish an up-front focus on reliability
  - Resulted in early transition to IEC standards
- Strong IEC standards have been
  - Key to minimizing setbacks as the industry rapidly expanded from infancy
  - Including a rapid transition to Asian manufacturing
  - Including rapidly changing Bills of Materials (BOM)
    - Continual changes to improve efficiency, lower cost, improve sustainability
    - Testing new BOMs to existing IEC standards does not prove reliability/lifetime but failures, outdoors testing, and root cause analysis provide a feedback loop to catch problems with and to continue to update IEC test protocols

Can IEC standards be highly valuable to CSP?

- CSP has fewer companies than PV and heliostats vary significantly: therefore, carefully consider where standardization is most beneficial
  - Beam characterization and metrology test procedures…Yes!
  - Mirror durability/reliability in various climates….Yes!
  - Support of Heliostat bankability? Are there a set of tests that can ***cost*** effectively support bankability while being ***flexible*** to a range of designs?
- CSP has worked within SolarPACES to develop important guidelines and is now working on various IEC standards
  - In some cases these are aligned with the whole industry but in other cases there is not cross cutting participation
  - A small minority from industry developing a standard is unlikely to be helpful!

PV: Sharing the Reliability Challenge

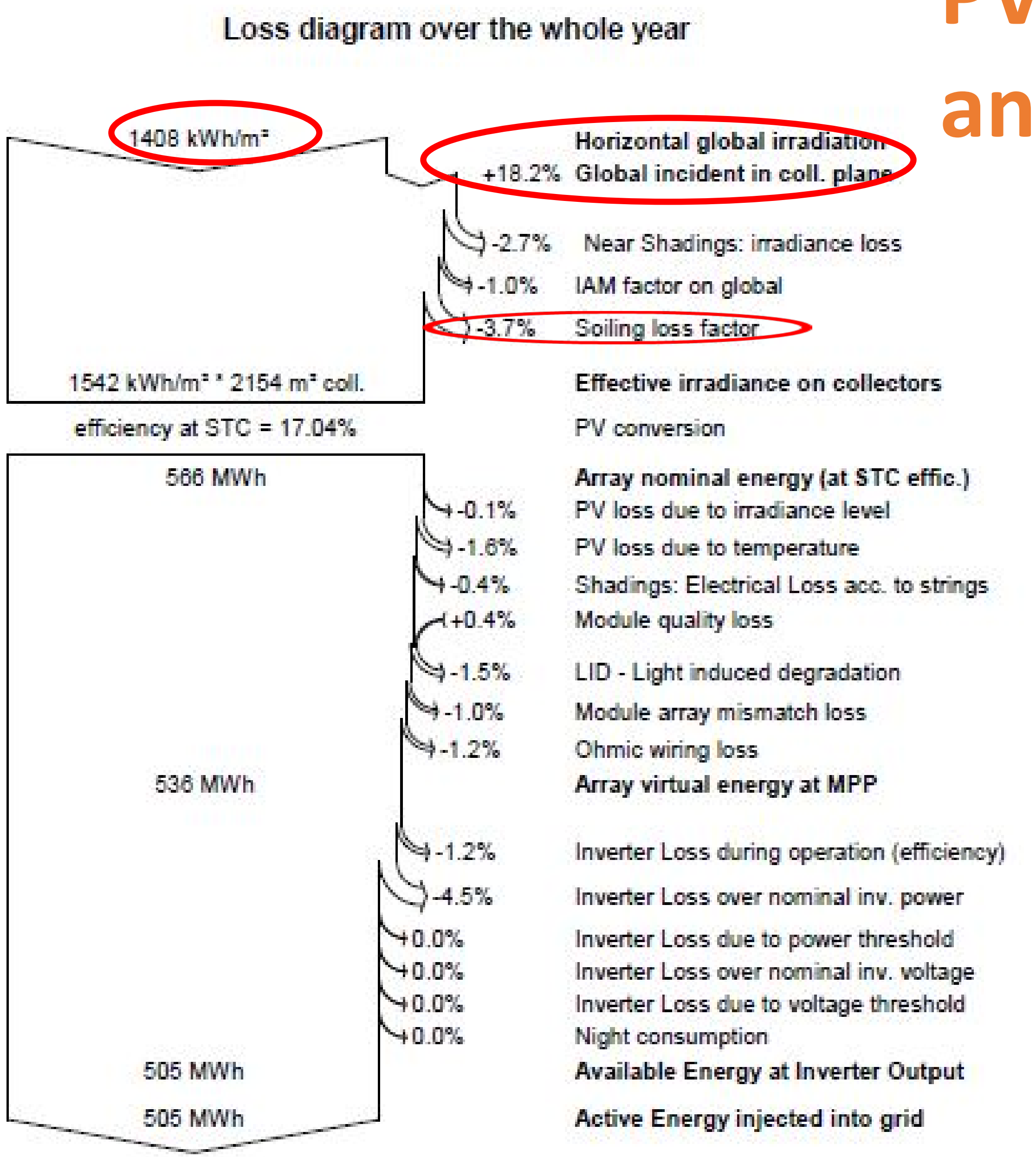
- As noted JPL set an early trend for focused reliability and standards work
- In the 1980's the U.S. DOE heavily supported thin film PV development and included funding for reliability work and standards specific to thin film modules
- Out of this work SERI held first thin film reliability workshop in 1986
  - This has transitioned over time to an annual workshop; the PVMRW to now PVRW
  - Why is this so important and why was this possible considering industry's motivation to hide problems?
  - Reliability workshops have provided a venue for safe sharing with a focus on common forward progress. Participation is required in order to attend. The industry realized this was a faster and more effective path toward collective success.

Can CSP collectively work on the reliability challenge?

- CSP reliability is different than PV but all companies still face the same challenge of long-term success in the harsh outdoors
- CSP has a smaller number of companies, sharing can be more difficult
- Setting up a workshop format that requires participation by all and organizer negotiates with invited parties on how they can participate without jeopardizing IP or other concerns.
- Motivation is the common need to reliably reduce cost and establish a continuous pipeline of CSP projects.
- Sharing will never be perfect but third parties like Heliocon, NREL, Sandia, ASTRI, Fraunhofer, and others have potential to bring industry together

PV performance Forecasting: an Independent Engineering (IE) Perspective

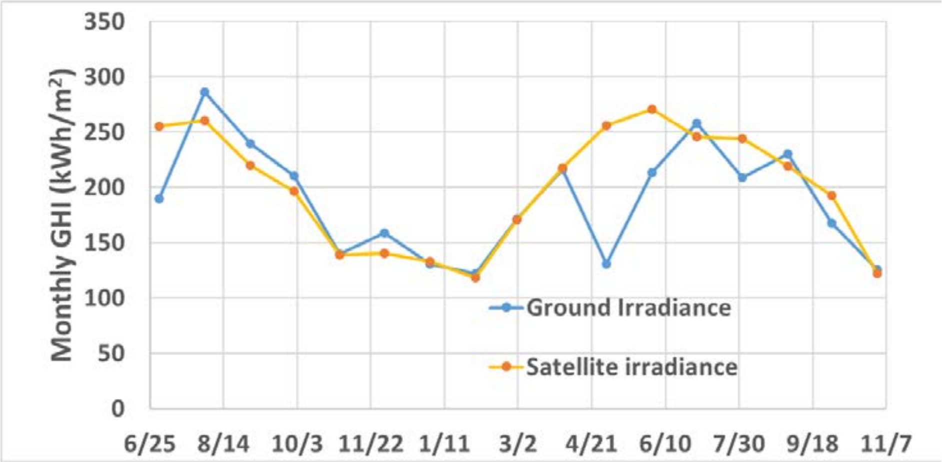
PV performance forecasting an IE perspective

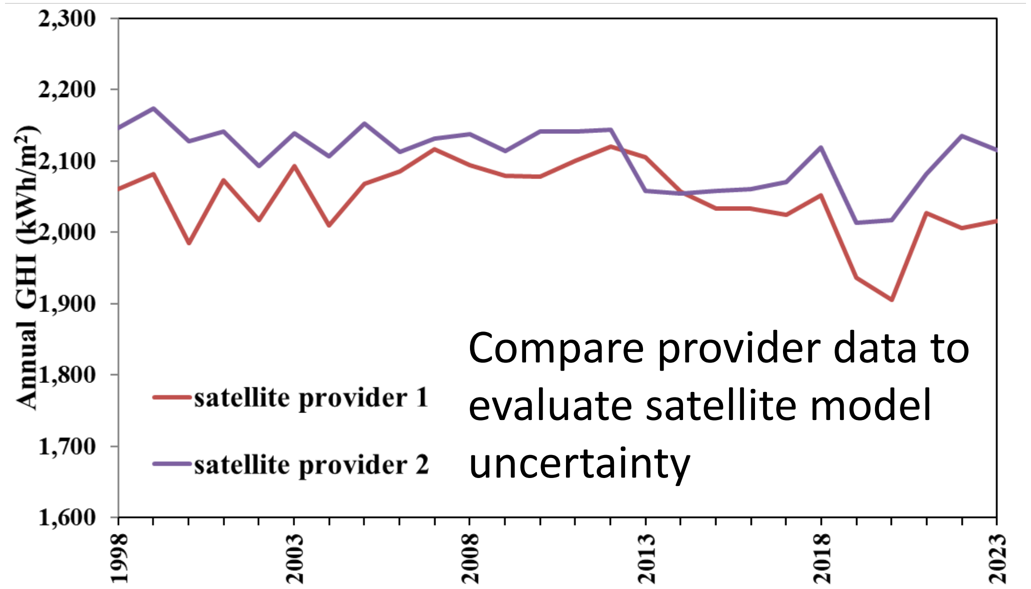


- IEs opine on modules, inverters, racks, foundations, build a plant model, etc. but maybe most relevant to CSP is 30-year performance forecasting (P50, P90, P10)
- Irradiance variability is typically biggest driver in differences in Pvalues
- Uncertainties associated with irradiance, PVsyst model, and degradation are the inputs to a Monte Carlo simulation (outputs are the Pvalues)
- Soiling is still not systematically included

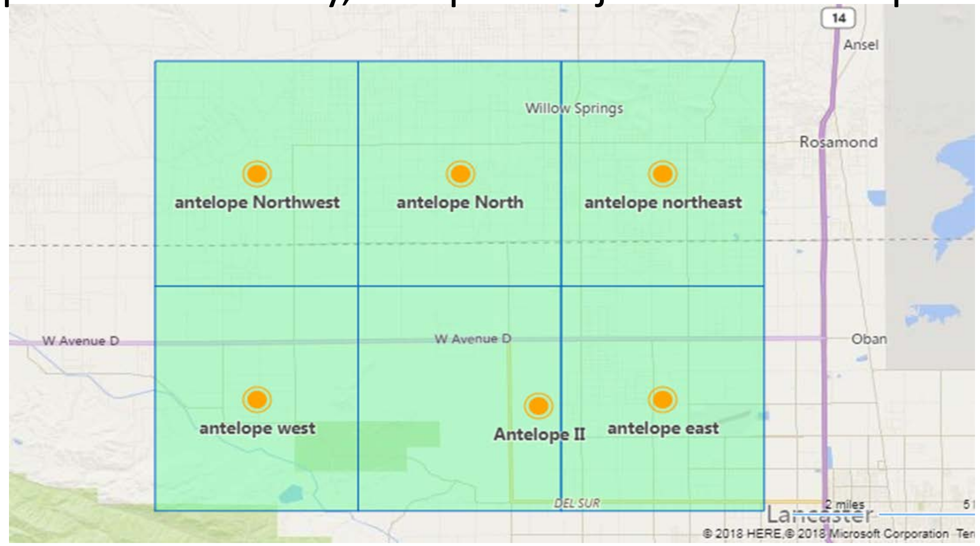
Irradiance variability/uncertainty, IE perspective

- Originally historic ground data sets, now satellite data sets from 1998 forward considered bankable (CPR, 3TIER, SolarGIS, PSM…..)
- Systematic error for GNI ~+/-(3-5)%, DNI ~+/-(7-10)%
- Large projects: 1 year ground validation
- 24 years into performance model to evaluate variability
- P50 equates with Typical Meteorological Year (TMY)





Spatial uncertainty, compare adjacent satellite pixels



Performance Forecasting and Potential CSP lessons

- IF IEs use sound models/statistics for 30-year PV forecasts WHY do underperforming plants still exist?
  - Satellite models are still evolving and significant bias can occur without careful analysis, ground validation, and complete uncertainty accounting
  - Optimistic inputs for system degradation
    - dependence on climate, technology, and operations and maintenance (O&M)
  - Soiling model inputs are not typically data driven and variability and uncertainty are NOT included

1. CSP performance variability and uncertainty has a first order dependence on DNI and therefore:
   a) learn the history/strength/weaknesses of the evolving satellite models
   b) understand/develop best practices to account for variability and uncertainty in the solar resource
   c) push for more focus on DNI improvements from satellite providers
2. Increase focus on accurate system degradation models
3. Must include soiling variability and uncertainty

PV Site Selection and Operations and Maintenance (O&M)

PV site selection (what NOT to do)

- PV sites selected based on land availability, tax incentives, business opportunity, and….
  - But **NOT** on long term performance, risk reduction, sustainability, cost effectiveness

- The Google image to the left shows several PV fields in California's Imperial Valley
- High solar resource and taxes incentives have made this region very lucrative for big solar fields
- Limited water availability and long-term drought have incentivized farmers to fallow land and lease or sell to PV developers
- Existing regulations have enabled conversion of Ag land to PV without studying the long-term implications
- Open desert < 25km away has shown 2-3% annualized soiling losses compared to 7-10% locally due to Ag operations
- Long term evaluations for sustainable use of land should be considered in conjunction with cost effectiveness of renewable technologies

PV site selection (what NOT to do)

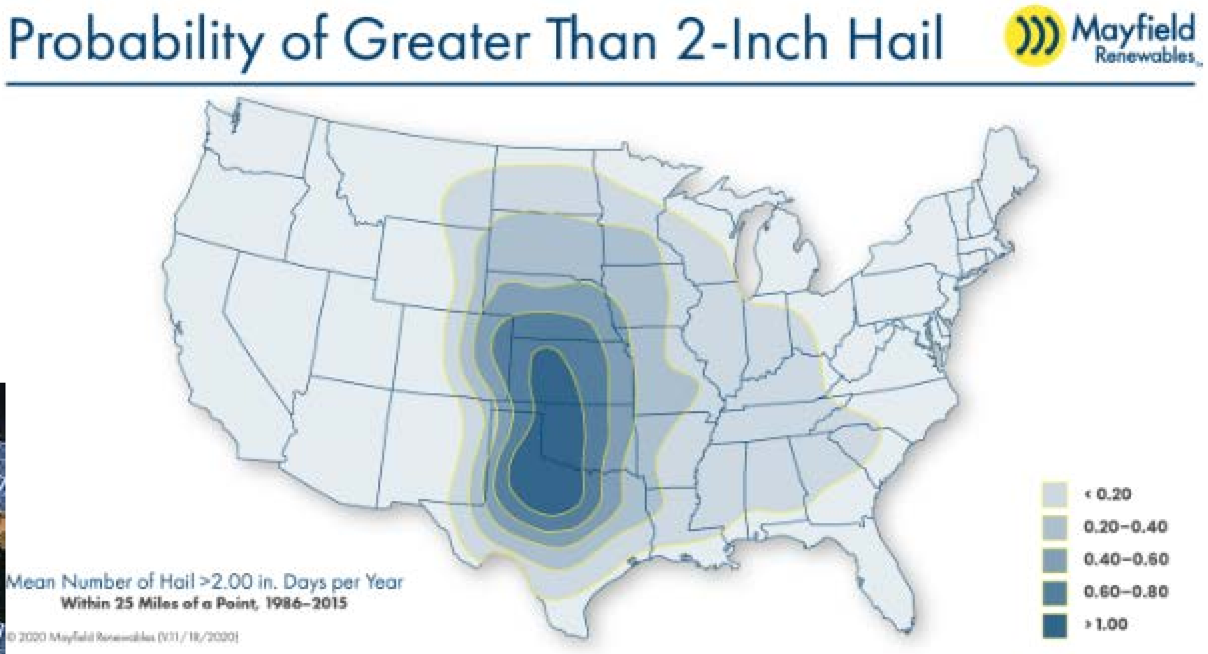
- Feed in tariffs or other incentives have resulted in farmers leasing the worst-case land to PV fields

- In the early 2010s farmland in Canada was converted to PV fields driven by a high feed-in tariff
- Rapid development led to incomplete consideration for transferring solar designs from hot dry regions to the wet and cold northern regions
- Various problems
  - Drainage issues
  - Erosion around piles
  - Water around piles have led to frost heave that has significantly misaligned whole rows of the PV field

PV site selection (what NOT to do)

- Insufficient consideration for worst case weather and insurance costs

  - 2019 hail storm in Texas damages 400,000 solar panels resulting $70 million in insurance losses
  - In the last few years the insurance industry has hardened to extreme weather risk that is expected to be impacted by climate change
  - Insurance premiums have increased as much as 400% in a short time
  - Some solar projects that were fully designed were canceled as they were no longer cost effective after the increase in insurance costs
  - Risks for damaging winds, flooding, hail, wildfires are all impacted by climate change.

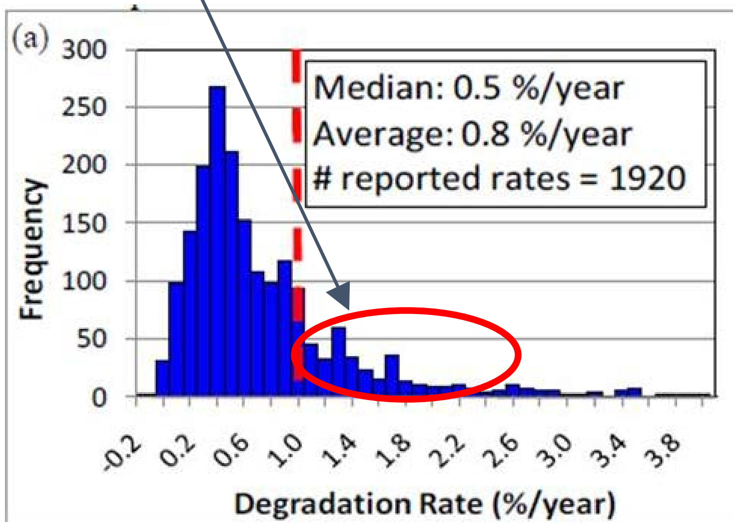


Operations & Maintenance (what NOT to do)

- In the early years O&M was often an after thought, some even convinced themselves that PV needed little or no O&M
- Data collected but often not examined
- O&M was reactive and not optimized
- In some plants tax equity drove plant owners to neglect O&M
  - Sell in 5 years; little motivation for the 30-year life as PV raced to beat fossil fuel costs there was a race to the bottom for O&M spending

Large soiling losses

Higher than expected degradation



Fires due to poor wire management or improper installation

Trackers not following sun

O&M improvements and lessons learned

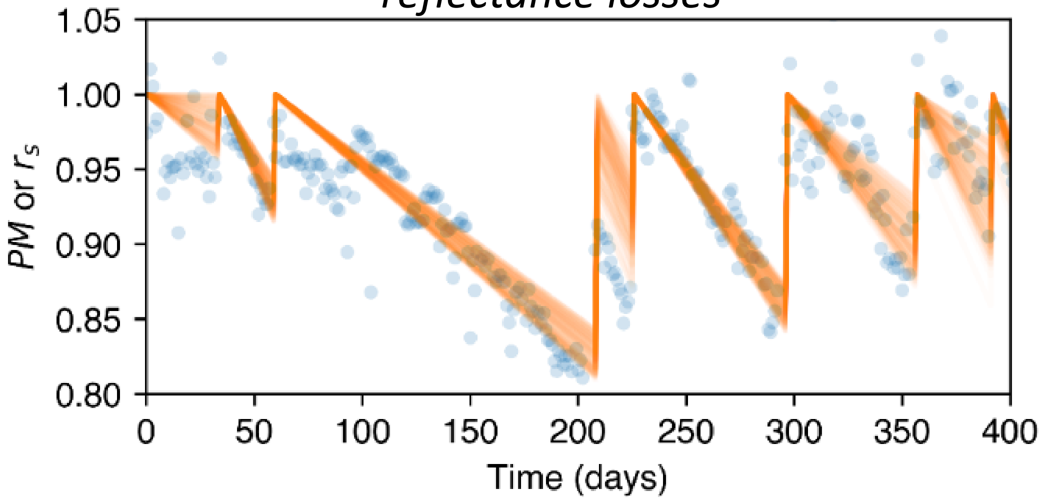
- NREL's comprehensive PV O&M guideline is worth reading and has relevant pieces to CSP https://www.nrel.gov/docs/fy19osti/73822.pdf
- O&M teams are incentivized by clear performance metrics and a plan over plant period of performance
- More O&M planning in: design, engineering, and construction
- Moving towards optimization of returns on dollars spent
- More automation, remote testing, to reduce labor and minimize truck rolls
- Data oversite and automated checks support proactive O&M

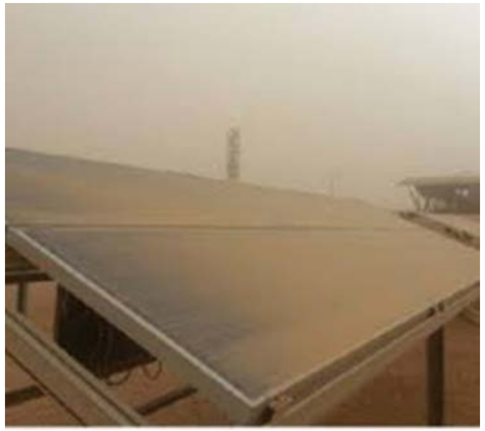
PV and CSP Soiling Research (remove the silos)

Soiling research (collaboration/removing silos)

- Large body of PV soiling research has been conducted in the last decade that parallels CSP soiling research
  - Extracting soiling losses from time series performance data
  - Development of automated soiling loss measurement equipment
  - Modeling soiling losses based airborne particulates, wind, humidity, localized pollution, system orientation and other parameters
  - Soiling mitigation and automated cleaning equipment

Extracting soiling losses from time series performance data,
Can transmission losses be translated to CSP appropriate reflectance losses





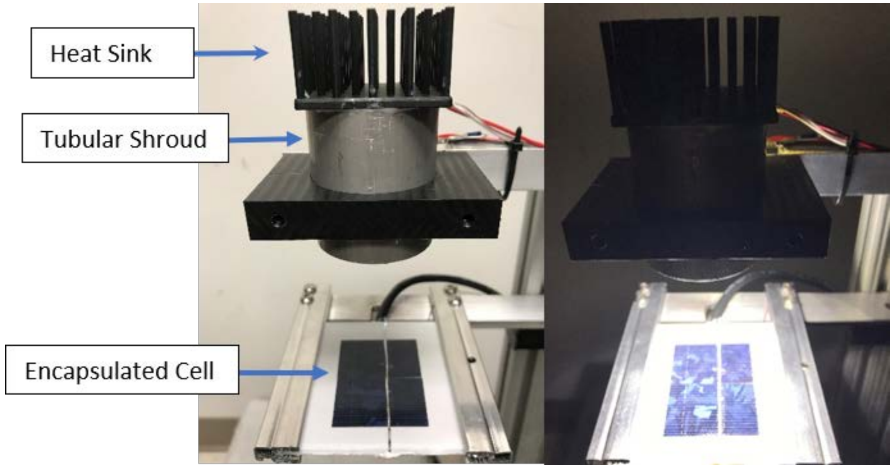
M. Deceglie, L. Micheli, M. Muller, "Quantifying soiling loss directly from PV yield," IEEE Journal of Photovoltaics, vol. 8. 2018.

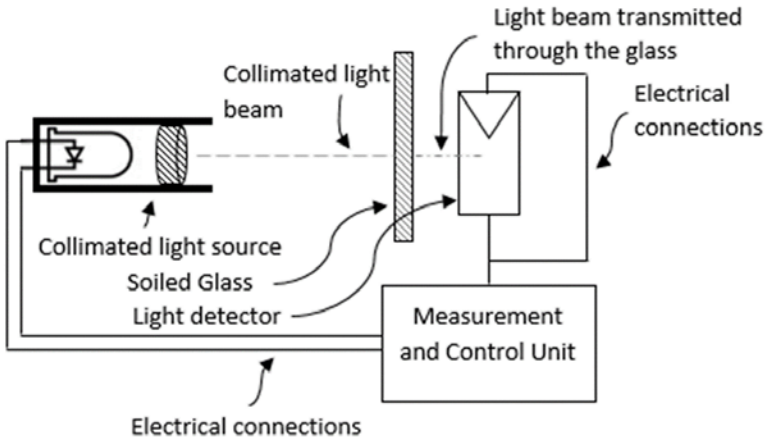
Soiling research (collaboration/removing silos)

Development of automated soiling loss measurement equipment

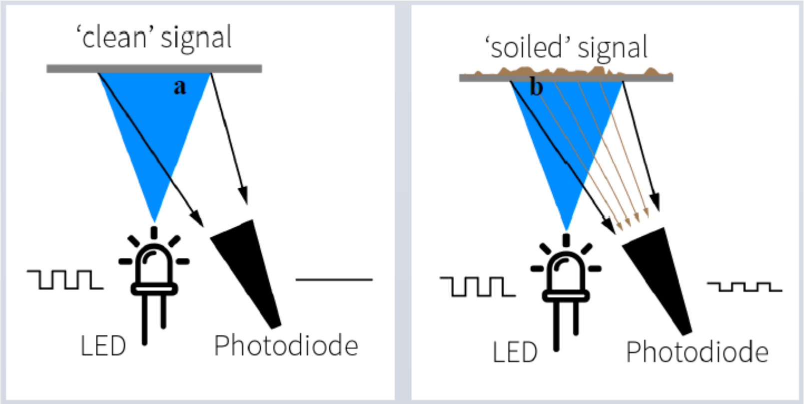
- Significant research went into each of these designs with a focus on PV but with modification each could work for CSP reflectance losses

DUSST by NREL



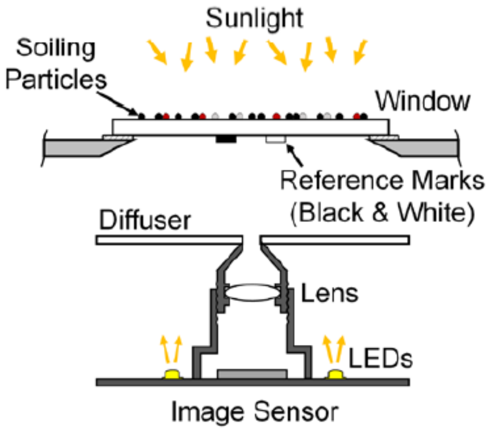


DustIQ by Kipp & Zonen



M. Korevaar et al. "Unique soiling detection system for PV modules," 35th European PV Solar Energy Conference, 2018.

MARS by Atonometrics



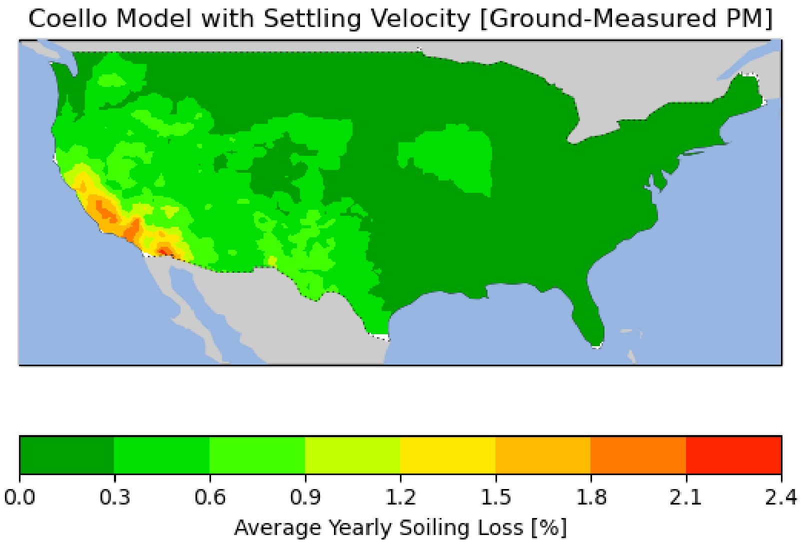
M. Gostein et al., "MARS soiling sensor," 35th European PV Solar Energy Conference, 2018

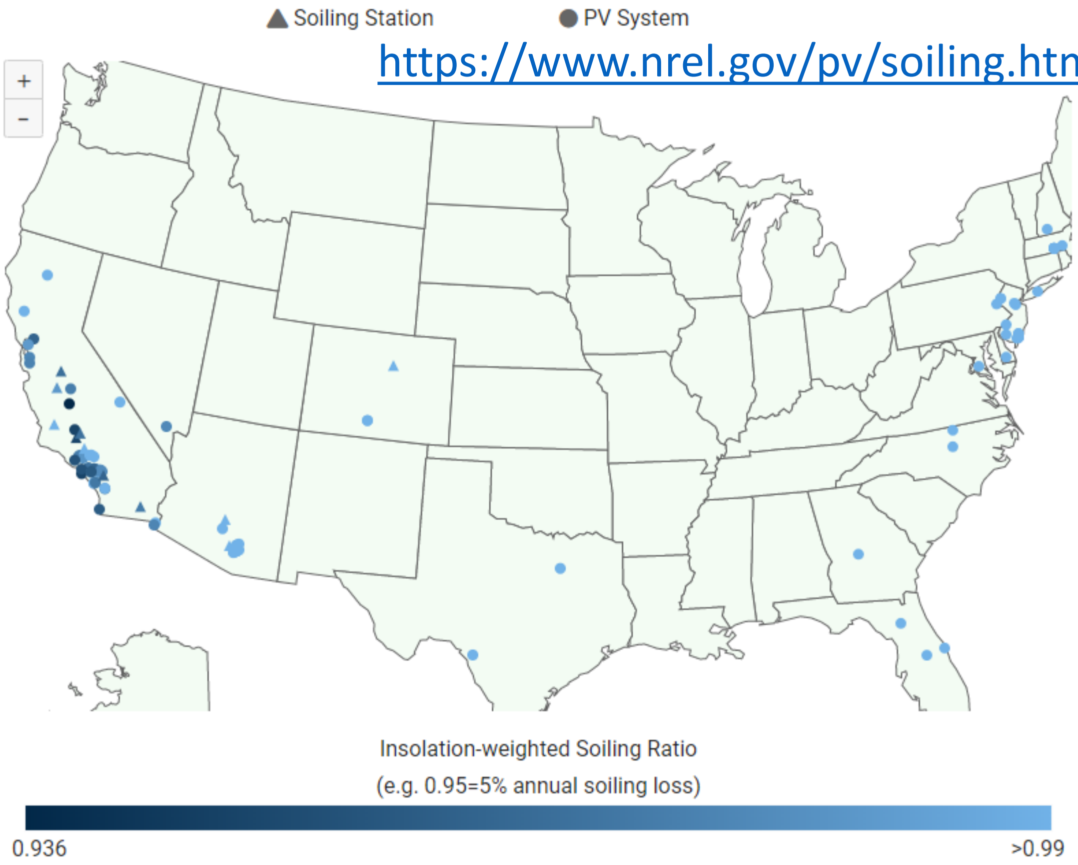
Soiling research (collaboration/removing silos)

Modeling soiling losses based on airborne particulates (PM) other factors

- Teams in both PV (NREL, Texas A&M Qatar, University of Jaen…) and CSP (NREL, Queensland University, Institute IMDEA Energy…) have been working on soiling models for a number of years but there has been relatively little cross communication
- PM and the physics of deposition and removal apply to both PV and CSP, it is only the final steps of translating the deposited particles to transmittance or reflectance losses that differences.

https://www.nrel.gov/pv/soiling.html



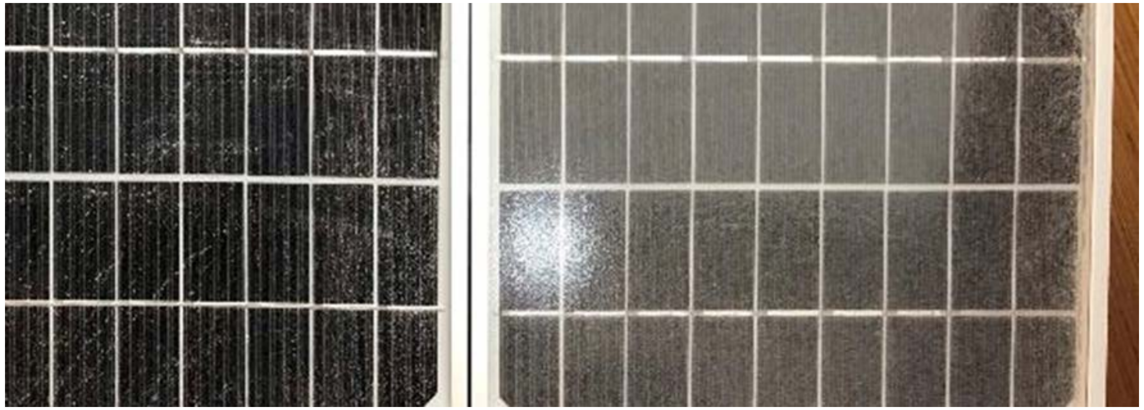


Soiling research (collaboration/removing silos)

Soiling mitigation and automated cleaning equipment

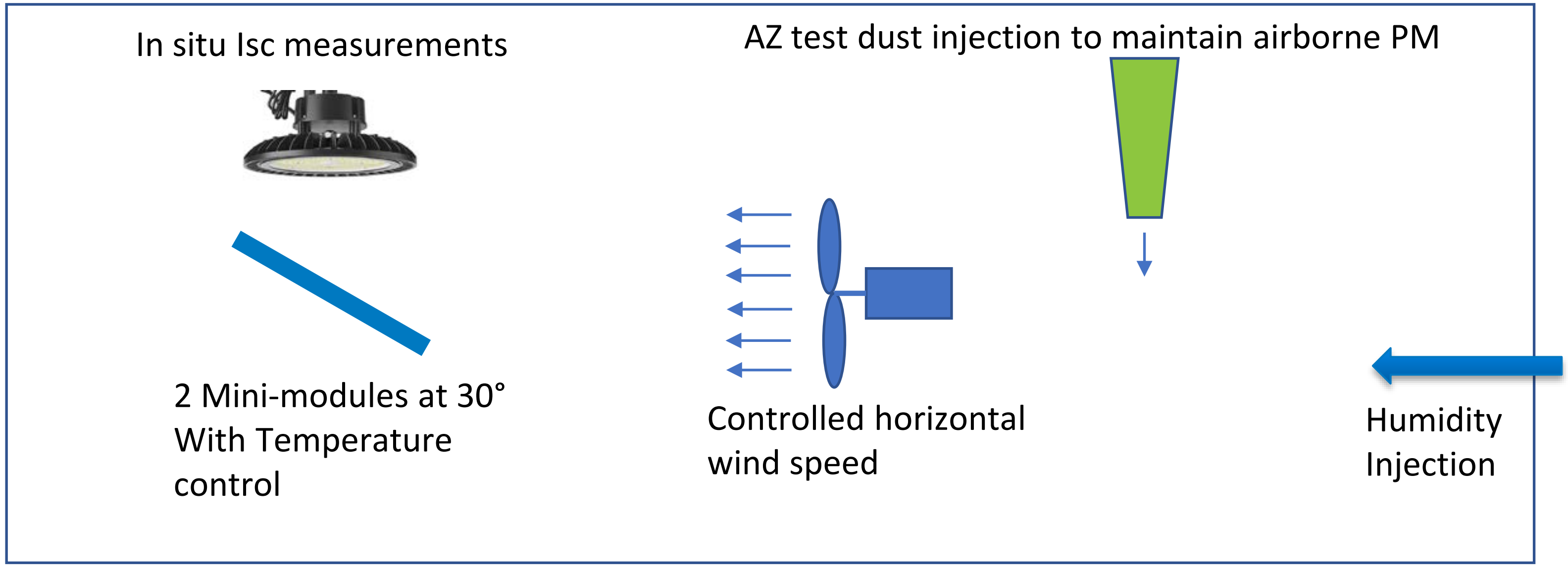
- High Labor costs and water availability have driven both PV and CSP industries to develop and test robotic cleaning equipment (truck/tractor type solutions and small robots in both PV/CSP but again relatively small crossover between this work)
    - Questions and research on surface damage, reliability, economics

- Anti-soiling coatings tested in both PV/CSP module
    - Applicability? effectiveness? Durability? economics?

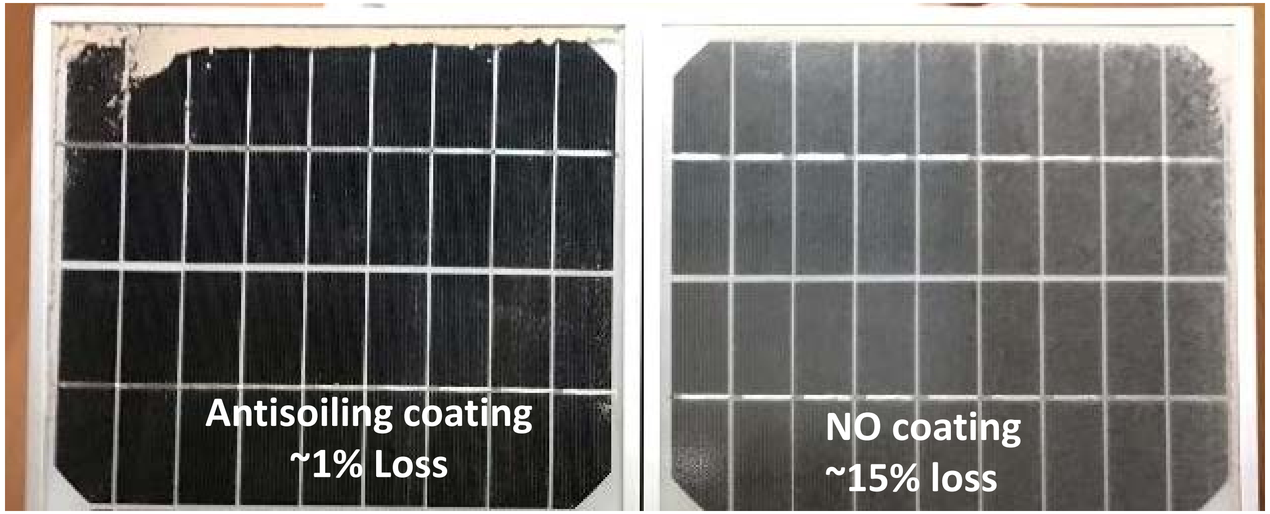


Soiling research (collaboration/removing silos)

Wind tunnel type soiling chamber for coating testing



Side-by-Side module test, Chamber RHset=75%, Module Temperature=45C



Existing IEC Standards that are Relevant to CSP

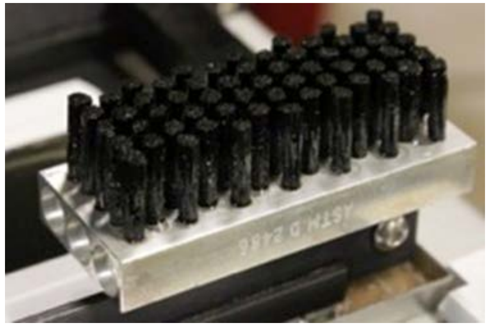
Relevant IEC standards

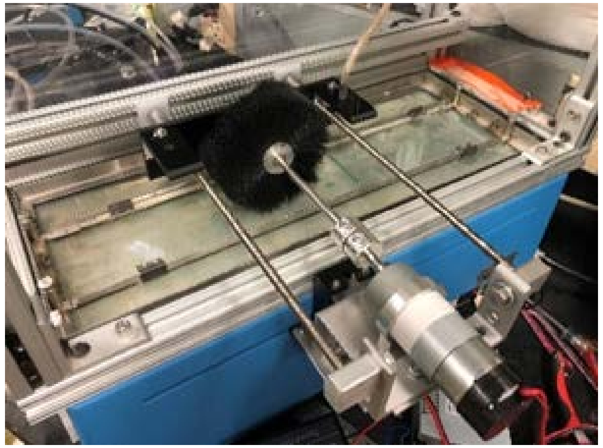
- IEC 62788-7-3 abrasion methods standard (focused on testing coating durability)→directly applicable to mirror surfaces

- IEC 62817 Design qualification of solar trackers (written with consideration for heliostats but does not include beam quality characterization)
  - ~ 10-15 tracker companies participated
  - Concentrating PV (CPV) experience → serious attention to heliostat reliability

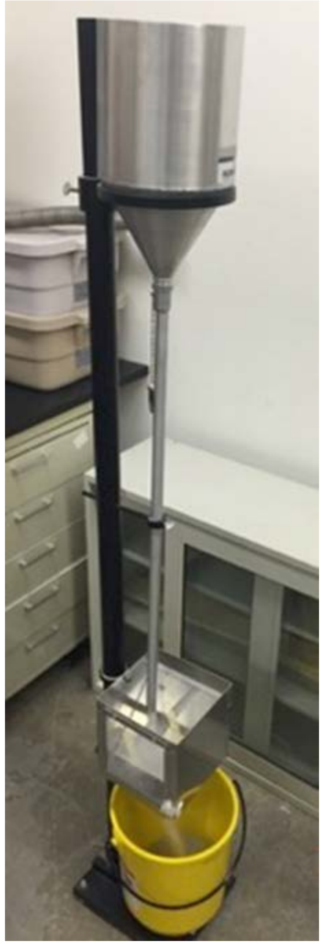
IEC 62788-7-3 Abrasion Methods

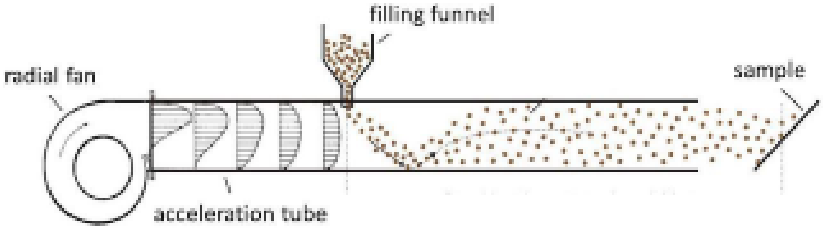
- Abrasives
  - dry
  - wet Slurry
- Linear brush test
  - manual cleaning brush on pole





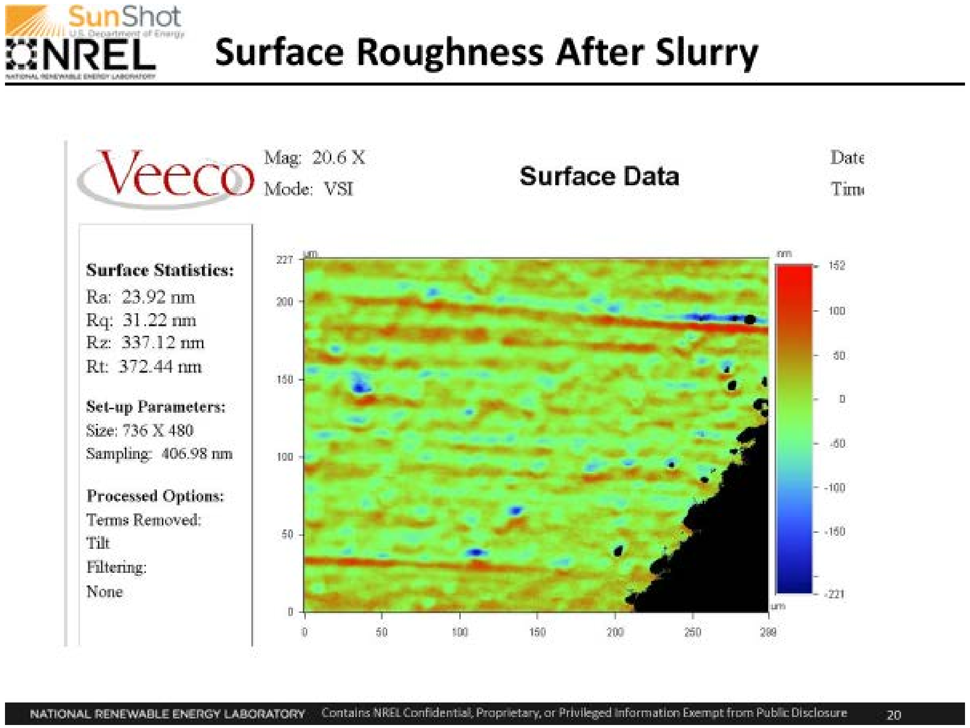
- Rotary brush test
  - robotic cleaning
- Falling sand test
  - natural abrasion from meteorological conditions
- Forced sand impingement test
  - blown sand severe storms

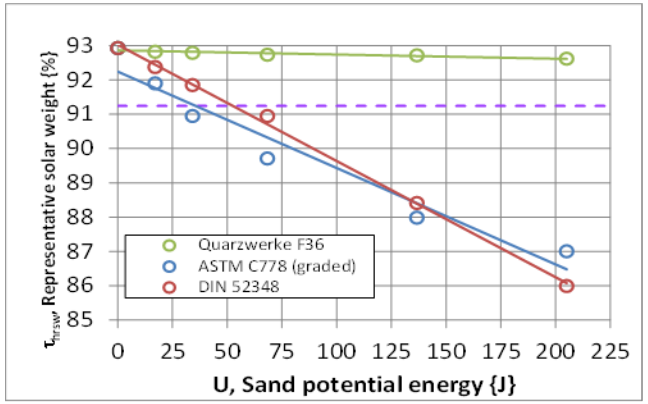


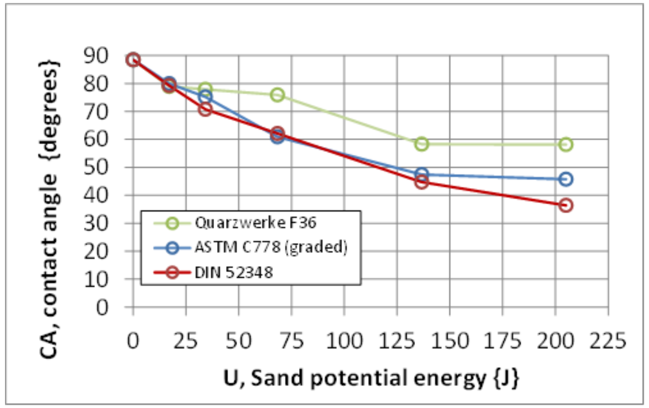


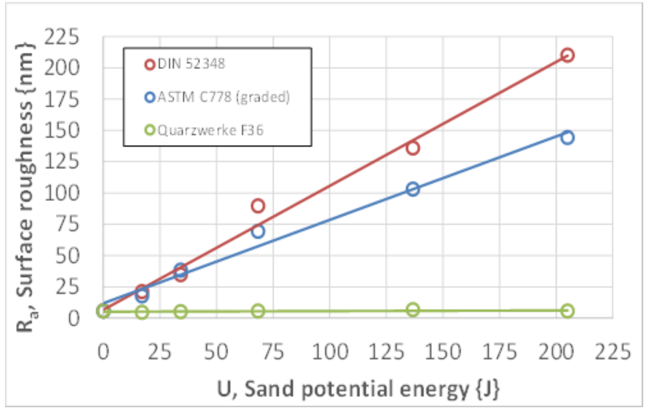
Characterizing coating damage

- Change in Transmittance
- Change in Reflectance
- Change in Surface Roughness
- Change in Contact Angle
- Change in Haze
- Change in Yellowness index
- Various imaging techniques









IEC 62817 (applicable to heliostats)

8.4.2 Control/drive train pointing repeatability test
8.4.4 Torsional stiffness, mechanical drift, drive torque, and backlash testing
8.5 Environmental testing (induce failures or infant mortality of the drive system, control system and associated wiring while operational in a wide range of environmental conditions)

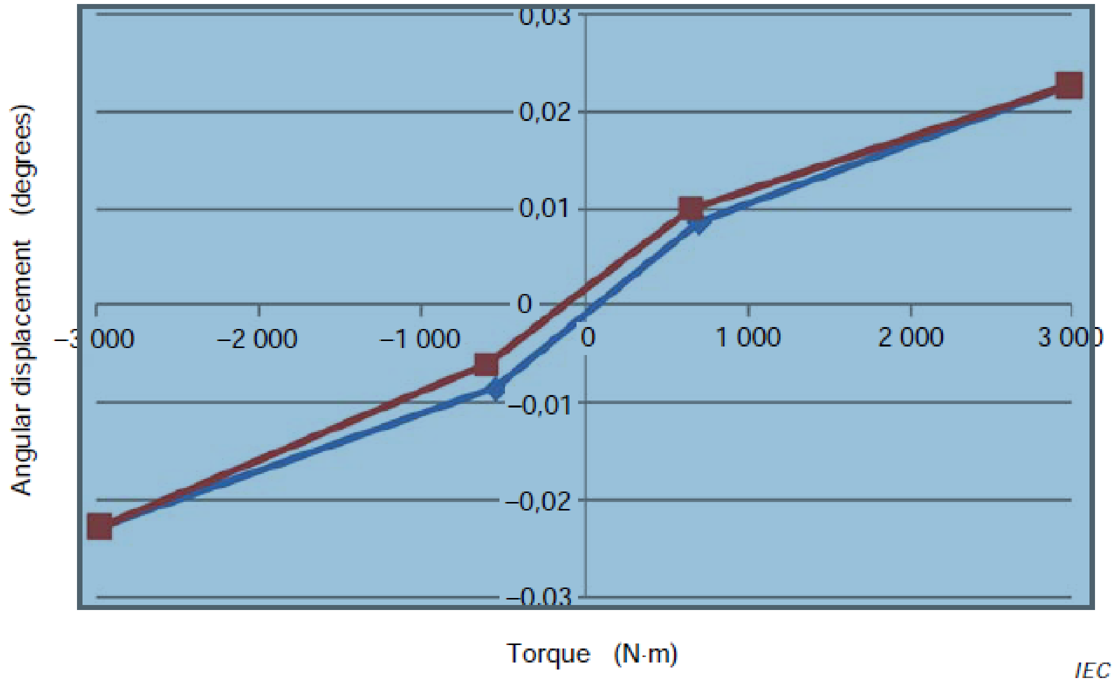


Figure 9 – Angular displacement versus applied torque to axis of rotation

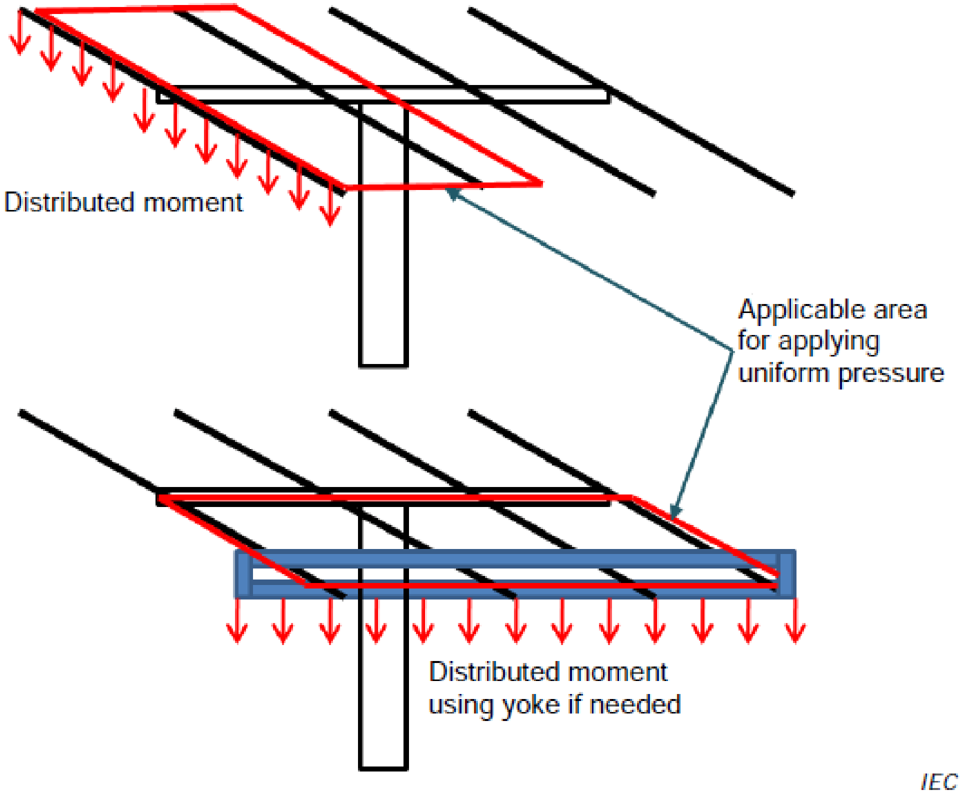


Figure 11 – Two configurations for extreme wind moment loading

IEC 62817 (applicable to heliostats)

- Control failures have been one of the highest frequency reported problems
- Heliostat control is a relatively simple mechanical/electrical engineering problem
- Heliostat reliability over 30 years is much more challenging
- Heliostat bankability is as important to CSP success as it was to CPV success
- CPV industry was beginning to emerge; NREL was testing products from 10-20 companies with 35% efficient modules
- High accuracy tracking was not considered bankable by many on the finance side

IEC 62817:2014 © IEC 2014 – 49 –

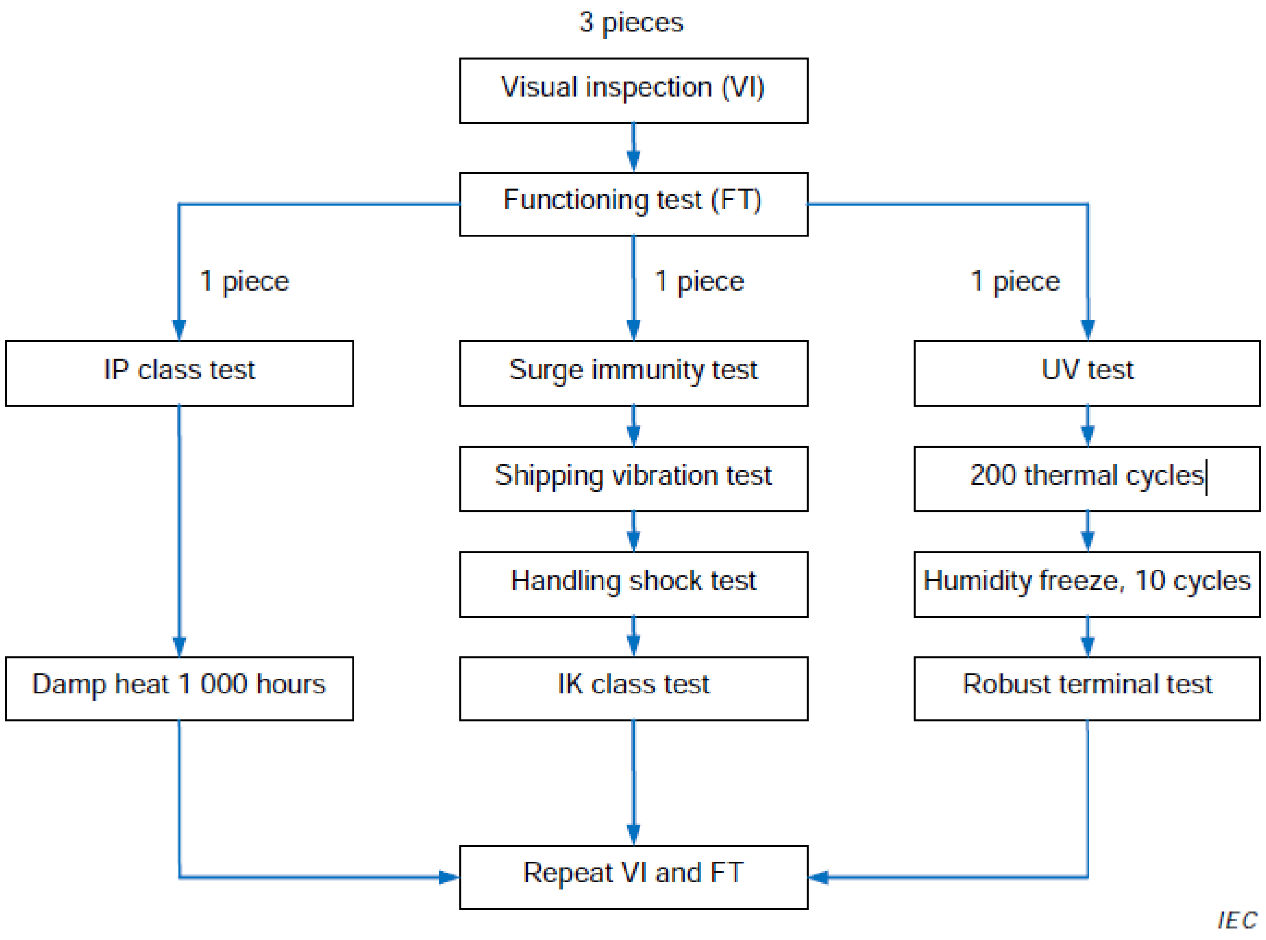


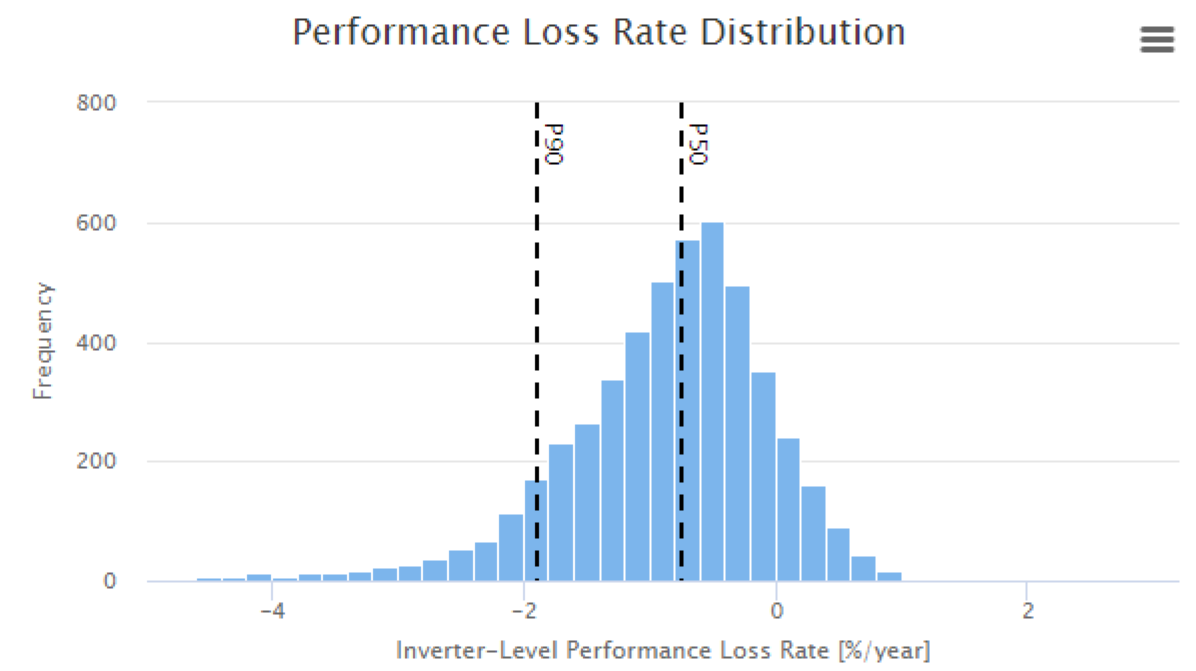
Figure 14 – Test sequence for electronic components

Benefits of Data Sharing

PV Fleets Performance Data Initiative

The U.S. DOE and NREL created the PV Fleet Performance Data Initiative to collect photovoltaic (PV) plant operation data in a secure, central database

- Significant benefits have come and continue to be forthcoming to the PV industry from this initiative
- While CSP is a much smaller industry collecting data in a secure location from as many CSP plants as possible can provide similar benefits
- Improve CSP modeling
- Reduce modeling uncertainty
- Better understand challenges and focus research dollars in the most critical areas
- Data on heliostat reliability issues that can drive improvements and demonstration of bankability
- Collection of O&M data to drive best practices guidelines



The current aggregated inverter-level PLR distribution. Median PLR for the fleet is −0.75 %/year based on 4915 inverters passing automated data quality checks.

Summary and Conclusions

- IEC standards have driven PV bankability, there is similar opportunity for CSP
- PV shared the reliability challenge and is now benefiting from data sharing, CSP has similar opportunity with funding/support/drive from a safe third party
- There are lessons learned in IE processes, site selection, and O&M that are directly applicable to CSP
- Common soiling research is ongoing in both PV and CSP and all would benefit if silos would be taken down
- There are existing IEC standards CSP can benefit from

Thank You!

Please ask questions and you are welcome to email for further discussion

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- Past seminar recordings and slides available here:
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- Subscribe to the seminar series or get in touch:
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Next Seminar Nov 9th!

HelioCon Seminar Series: Mitigating Unconscious Bias in Work Teams
Speaker: Anelisa Simons, SNL
When: 1-2pm MST Wednesday Nov 9th
Zoom:https://nrel.zoomgov.com/j/1606740022?pwd=cWdmblYrY29QSzBtYnZDMlVmWlAxQT09