Conduct Performance Validation of the Electrodynamic Shield (EDS) Induced Cleaning Under Realistic Environmental Soiling Conditions

Cooperative Research and Development Final Report

CRADA Number: CRD-21-17861

NREL Technical Contact: Lin Simpson

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5K00-84117
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NOTICE

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Cooperative Research and Development Final Report

Report Date: September 21, 2022

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: SUPERClean Glass Inc.

CRADA Number: CRD-21-17861

CRADA Title: Conduct Performance Validation of the Electrodynamic Shield (EDS) Induced Cleaning Under Realistic Environmental Soiling Conditions

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Solar Energy Technologies (SETO)

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$75,000.00
TOTALS	$75,000.00

Executive Summary of CRADA Work:

NREL will work with the Participant to perform accelerated long-term durability and other standard durability tests for prototypes to help demonstrate the reliability of the technology for PV applications. NREL will test commercially relevant-sized prototypes under realistic environmental soiling conditions to correlate dust removal efficacy for improving the PV output under standard solar conditions. Measurements will include voltage-current characterization in solar simulators before and after dust cleaning.

CRADA Benefit to DOE, Participant, and US Taxpayer:

- Assists laboratory in achieving programmatic scope competencies
- Uses the laboratory's core competencies

Summary of Research Results:

TASK DESCRIPTIONS:

NREL completed all tasks assigned in the initial CRADA, with no revisions required. These included:

Task 1: Utilize NREL soiling chamber to validate dust removal efficiency that was previously measured by SUPERClean Glass Inc.

Task 2: Measure voltage-current curve before and after activating Electrodynamic Shield Electrodes (EDS).

Task 3: Conduct parametric testing under different soiling and environmental conditions.

PARTICIPANT (SUPERClean Glass Inc.) completed all tasks assigned in the initial CRADA, with no revisions required. These included:

TASK 1: Provide pertinent samples for performing the different tests.

TASK 2: Work with NREL to determine appropriate testing conditions.

TASK EXPLANATIONS:

SUPERClean provided an initial set of samples (Table 1), as well as electronic equipment and directions for performing electrostatic cleaning using the samples. SUPERClean and NREL also discussed and identified a set of durability tests to perform on the samples provided.

NREL performed a set of sample characterizations prior to and after the tests were performed. The characterizations prior to the testing provided a baseline for comparison during and after the testing.

Table 1. Electrodynamic Samples Provided by SUPERClean

Labels	Test
Sample 1	IEC61215 Standard Humidity Freeze (HF): 10 cycles from +85C, 85% RH to -40C; Cycling (TC): 50 cycles -40C to +85C;
Samples B (Broken)	IEC61215 Standard Damp Heat (at +85C, 85% RH.)
Sample 3	IEC62788-7-3 Standard: Linear Abrasion (LA) test
Sample 6	Cleaning Efficiency Test
Sample 7	Cleaning Efficiency Test
Sample 2 (Extra as a Backup)	Cleaning Efficiency Test

TASK 1: Utilize the NREL soiling chamber to validate dust removal efficiency that was previously measured by SUPERClean Glass Inc.

As shown in Figure 1 through 4 NREL used its artificial soiling system to uniformly and repeatably deposit a layer of dust on the sample surfaces to characterize how well SCG-EDS cleared it away. The procedure was to correlate dust loading using Keyence optical microscopy, direct optical light transmission %, and a solar simulator that measured PV performance (laminated sample).

NREL observed that dust was removed from the surfaces with the SCG-EDS.This included 3 samples with electrodynamic coatings that were tested for removing soiling.

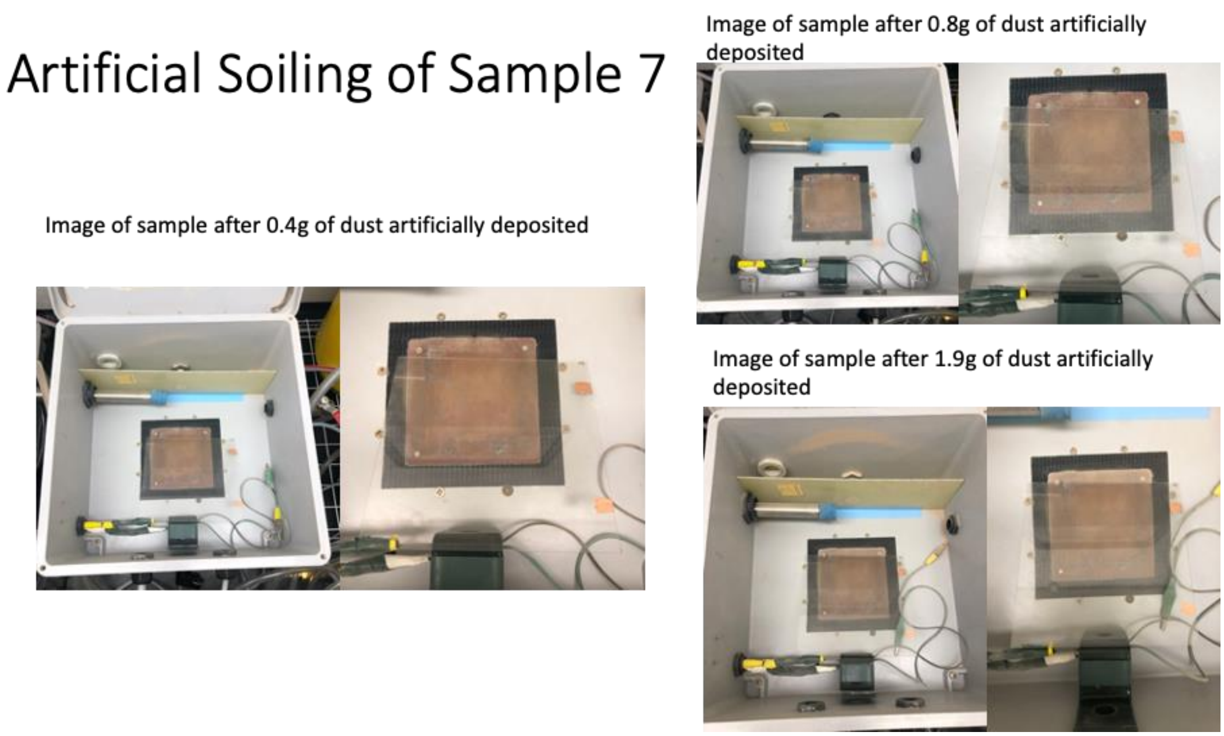


Figure 1. Images of Sample 7 after being artificially soiled.

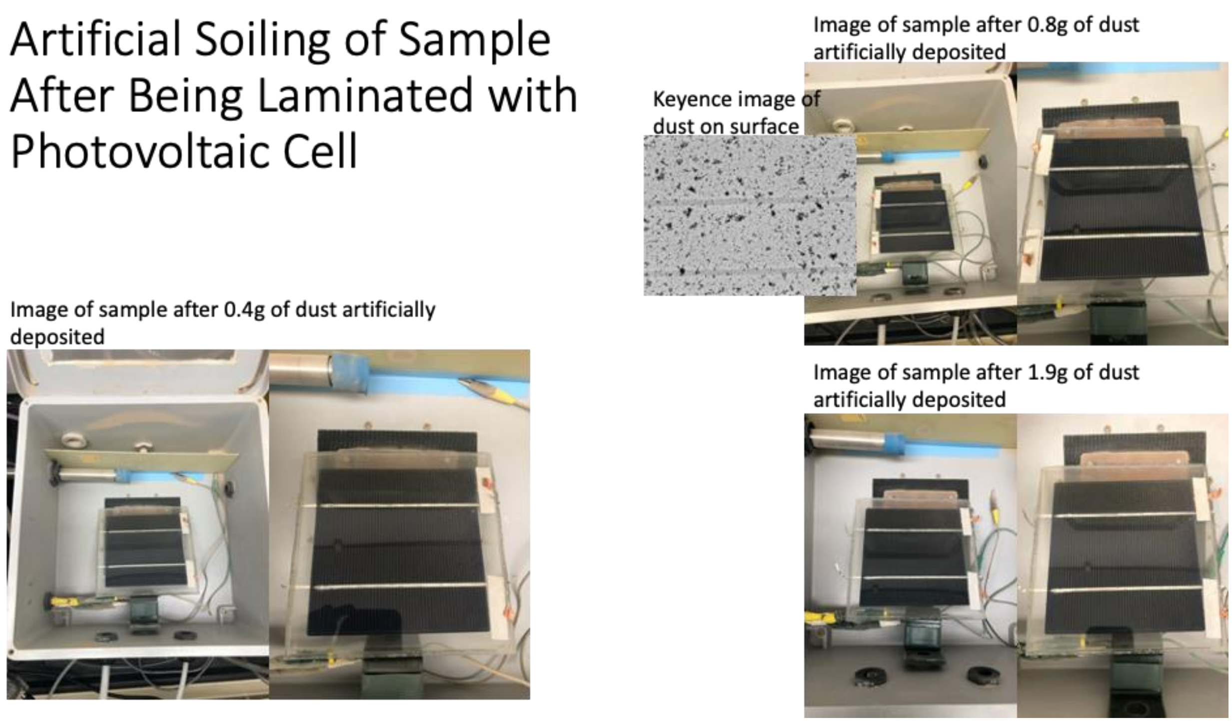


Figure 2. Figure of sample laminated to PV cell and being artificially soiled.

<u>TASK 2</u>: Measure voltage-current curve before and after activating Electrodynamic Shield Electrodes (EDS)

As shown in Figure 3, the SCG-EDS was successfully laminated with a photovoltaic (PV) cell using techniques similar to that used in industry and illuminated voltage-current measurements were performed with a solar simulator before and after soiling, and after the dust was removed with the EDS system. The initial results showed that the samples were soiled to a level that reduced up to ~6% of the PV output. Subsequently, the SCG-EDS removed nearly all the soiling, resulting in PV output returning to within ~1% of a fully clean surface (no dust).

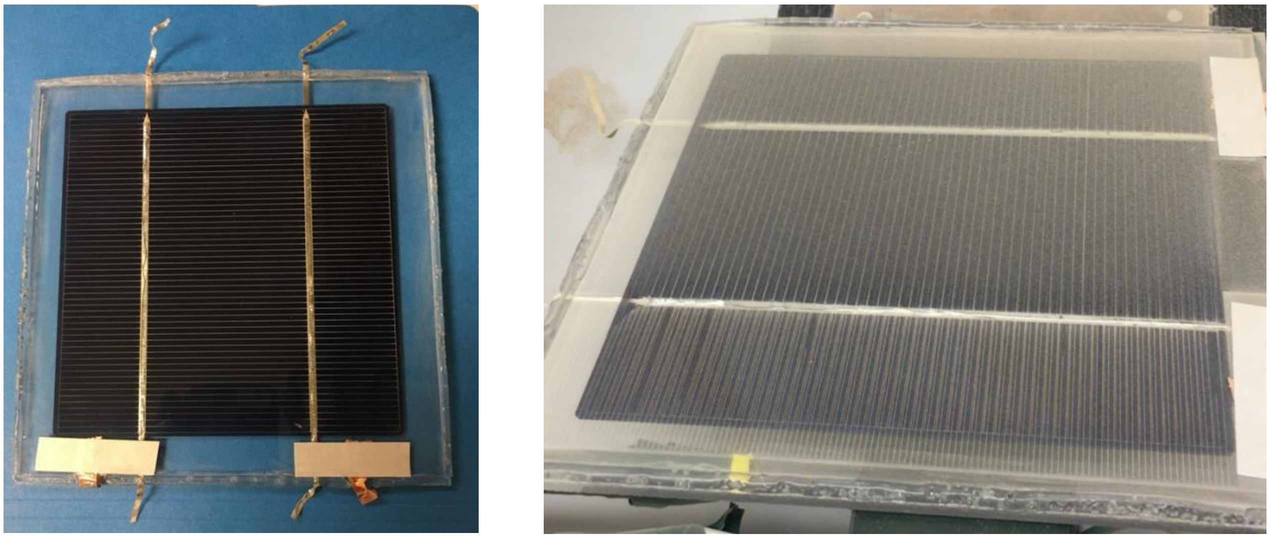


Figure 3. Pictures of SCG-EDS sample laminated with a photovoltaic cell before (left) and after deposition of dust layer (right).

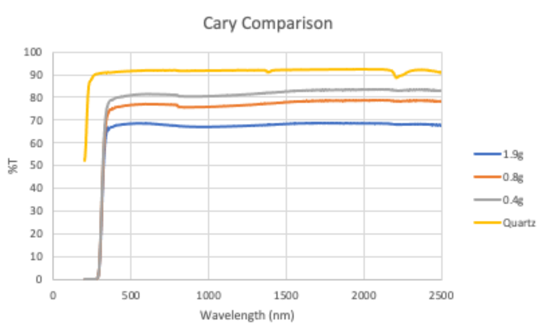
Results of Artificial Soiling of Sample 7

- Keyence Comparison

Soiling Mass	Average Particle Count	Average PAC	Average Perimeter Std Dev	Average Circularity
0.4g	15673.4	10.5	14.38	25.56
0.8g	33520	22.82	16.74	17.06
1.9g	14111.2	22.49	27.63	18.67

Good correlation between average percent area coverage (PAC) and transmission (%T) for different amounts of artificial soiling for 0.4 g and 1.9 g..

- Cary Comparison



"Quartz" is used for normalization

Figure 4 Measurement results of sample 7 with different amounts of soiling.

<u>TASK 3</u>: Conduct parametric testing under different soiling and environmental conditions

Four types of tests were performed to evaluate the potential durability of the SCG-EDS coatings on the glass samples.

1. IEC-61215 Thermal Cycling Test ((50 cycles from –40 °C to +85 °C), and

2. Humidity Freeze Test (10 cycles from +85 °C, 85 % RH to –40 °C)

Figure 5 shows that no observable visible damage was done to the SCG-EDS samples after thermal cycling or humidity freeze tests.

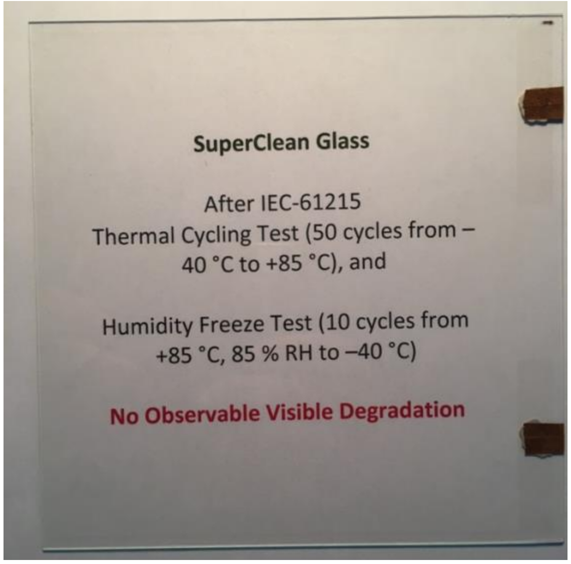


Figure 5. Picture of SCG-EDS sample after completion of thermal cycling and humidity freeze tests. This picture shows the sample was just as transparent as it was before being tested, and no additional haze or other indications of degradation are observed.

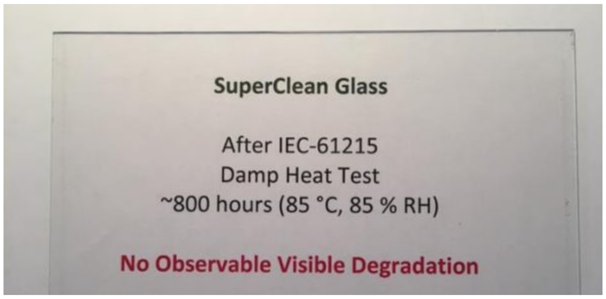


Figure 6. Picture of SCG-EDS sample after completion of ~800 hours in damp heat test. This picture shows the sample was just as transparent as it was before being tested, and no additional haze or other indications of degradation are observed.

3. IEC-61215 Damp Heat Test ~800 hours (85 °C, 85 % RH)

Figure 6 and 7 shows that there was no observable visible degradation of the SCG-EDS coatings after completion of ~800 hours and 1000 hours of the tests.

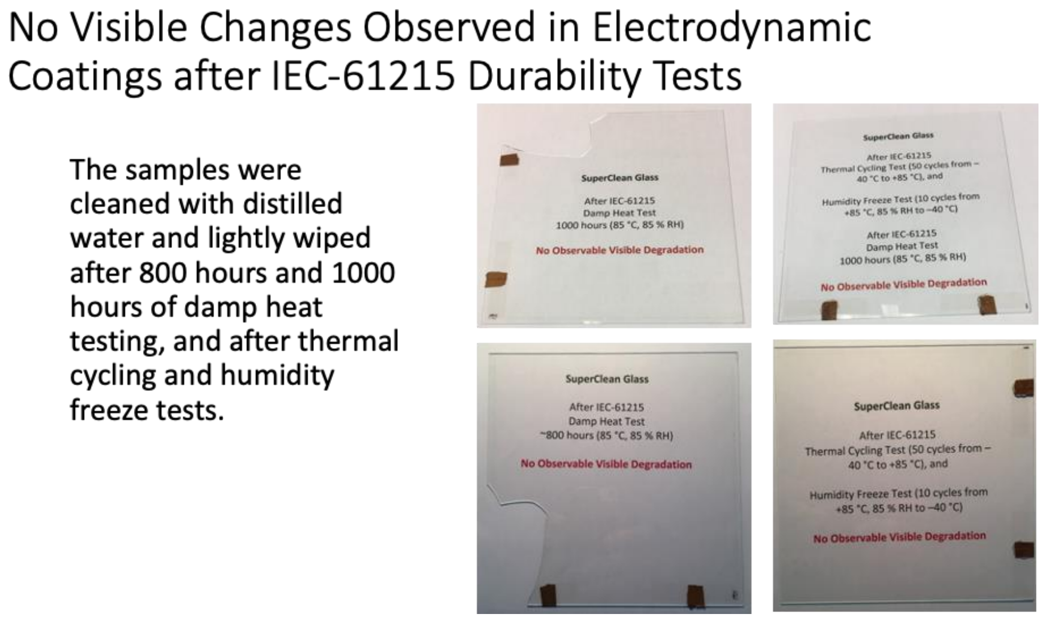


Figure 7. Images of samples after different durability tests.

4. IEC- Linear Brush Abrasion Test (100 cycles, aqueous dust slurry).

Figure 8 shows that there was no observable visible degradation of the SCG-EDS coatings after completion of the different tests. This included a linear abrasion test where a brush was pushed over the surface back and forth 100, 500, and 1000 times. These tests are part of a suite that are routinely performed with photovoltaic modules to evaluate how well coatings and other components may last in normal outdoor field operations.

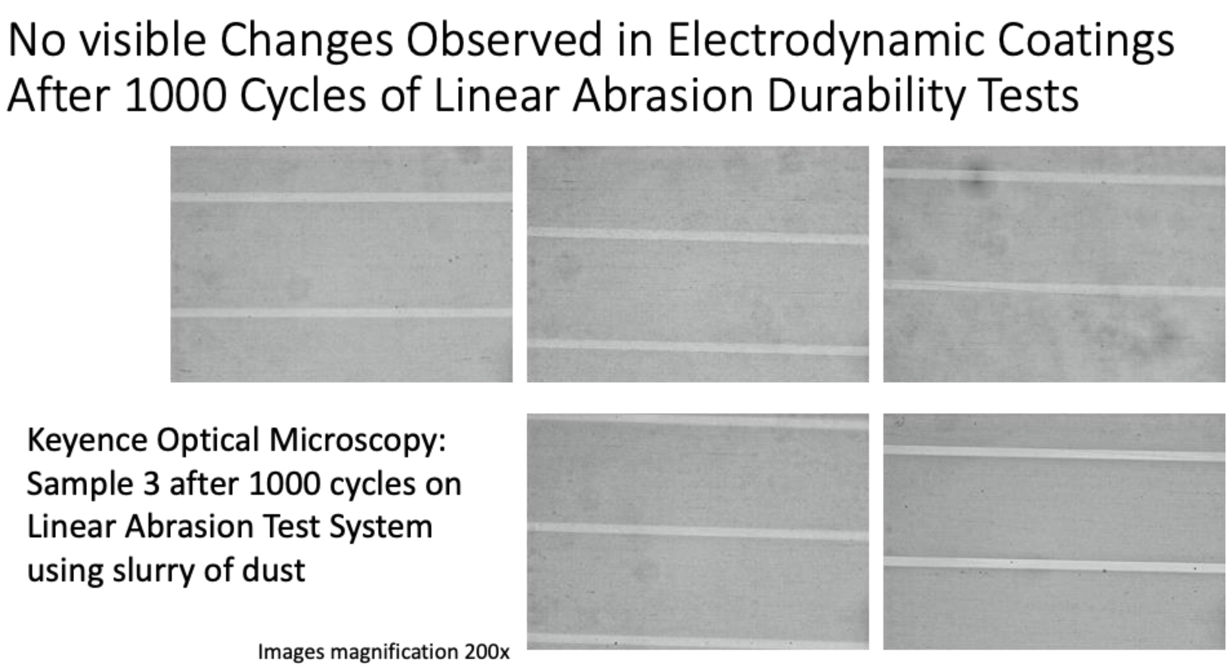


Figure 8. Images of samples after 1000 cycles of abrasion testing.

TASK 4: **CRADA Final Report – Preparation and submission in accordance with requirements.**

This report meets the requirement for the CRADA Final Report.

Summary/Conclusion:

Overview of Analyses Performed

Wyco: Optical surface roughness measurements

- No significant changes observed comparing samples as received and after abrasion testing

Keyence optical microscopy images

- No significant changes observed comparing samples as received and after abrasion testing
- Correlation observed between measured "percent area coverage" and amount of dust used

Cary 7000 Spectrophotometer: Percent optical transmission

- Correlation observed between measured "percent transmission" and amount of dust used

Durability Measurements

- Linear abrasion; Reference - https://www.nrel.gov/docs/fy16osti/66334.pdf, https://doi.org/10.1016/j.solmat.2020.110757
  - No scratches or degradation of coatings were visibly observed after 1000 cycles of linear brushing with an aqueous slurry of dust
- No visible degradation observed of coatings after longer term durability tests
  - IEC-61215 Damp Heat Test
  - IEC-61215 Thermal Cycling Test (50 cycles from -40 Celsius to 85 Celsius
  - IEC-61215 Humidity Freeze Test (10 cycles from 85 Celsius, 85% relative humidity to -40 Celsius

Electrodynamic Cleaning

- Initial tests showed dust coming off the samples once the electricity is applied.

Subject Inventions Listing:

None

ROI #:

None