Final Report

Evaluation of Solaris Hydrobotics's Cleaning Robot: Accelerated Testing with GCL Solar Modules

PI Report Number: G2021129Pa _V1

Berlin, 06.10.2021

Customer

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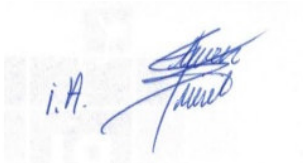
Created by:	 Romain Pénidon, Senior Consultant	Approved by	 Steven Xuereb, Executive Director

Disclaimer

Document History

Version	Date	Comments
V1	06.10.2021	First release to Customer

Remark

References to the laboratory report (G2021129La_V1) are made when it is relevant. The laboratory report contains all detailed test results and is fully shared with the Customer as Appendix to this report.

Table of Contents

Appendix

1. Executive Summary

This test report evaluates the impact on a PV module of the automatic cleaning device from Solaris Hydrobotics applied three times per week over a 25-year period (i.e 3900 cycles). The laboratory tests were conducted on a PV module from the supplier GCL Solar of the type GCL-P6/72H330, which is a crystalline monofacial glass-backsheet framed PV module.

The accelerated cleaning simulation was performed at the Solaris Hydrobotics R&D facility in Israel by applying a specific cleaning procedure under the supervision of the PI Berlin local representative (three spontaneous inspections: 20th, 29th and 31st August 2021).

The simulation was intended to replicate the conditions of the implementation of the cleaning procedure in a PV plant. Deployed in the PV plant, this cleaning solution runs using softened water; as a reverse osmosis was not available at the testing facility, the cleaning simulation was performed at night avoiding creation of scaling. Instead of using standardized test dust or sand as typically used during such an assessment, Solaris Hydrobotics opted for CaCO3. Calcium Carbonate or CaCO3 is the carbonic salt of calcium; the AVGIL 128 provided by Microgil was used. An amount of 40 g of CaCO3 powder was distributed across each module test specimen per sand event. The module characterizations (initial and final) were carried out at PI Berlin's accredited laboratory in Berlin, Germany.

Summary of results for Solaris Hydrobotics´s cleaning robot

The tests conducted on the modules indicate that the cleaning procedure does not generate obvious appearance defects and nor has influence on the ARC within the first 25 years of cleanings at the rate of 3 cleanings per week.

In terms of the mechanical impact on the solar cells, the results have shown that this cleaning procedure has no recognizable negative impact, which can be considered as very good.

2. Introduction & Motivation

Photovoltaic (PV) modules in operation are exposed to environmental influences which can have a negative influence on the power output of modules. Soiling due to sand is a major factor in arid areas which can lead to significant yield losses within a short time period, especially after sand storms. Solaris Hydrobotics offers alternative, and water powered cleaning solutions compared to the standard manual water-based method applied in solar plants.

To increase the efficiency of PV modules, anti-reflective coatings are applied on top of the front glass. Cleaning of modules can lead to an accelerated removal of these coatings but also to a damage of the glass surface, mostly in the form of scratches. The objective of this project report is to assess the impact of the Solaris Hydrobotics cleaning robot cleaning on PV modules from the manufacturer GCL Solar. The focus will be on the ARC coating and the

glass surface, mechanical influence on the cells as well as on the electrical characteristics (in particular the power output).

This report summarizes and comments the results of the laboratory testing services.

3. Scope of Work

3 GCL Solar modules selected by the module supplier were sent to PI Berlin testing lab for initial characterization. The initial characterization consists of stabilization, visual inspection, power output measurement, electroluminescence image and reflectance measurements. Afterwards 2 modules out of the 3 were installed on a test rack with the cleaning robot to simulate a three times per week cleaning over a 25- year period. The third module mounted on similar test rack in a similar environment was used as a control module, no cleaning and no send event. Once the simulation has been finished the 3 modules were analysed with characterization measurements. The accelerated cleaning simulation is performed at the Solaris Hydrobotics R&D facility while the module characterization is performed PI Berlin testing facility.

4. Methodology

4. 1. Test definition

Solaris Hydrobotics defined the testing procedure; PI Berlin was informed prior to the experiment started. The following testing conditions were applied:

- AVGIL 128, a natural calcium carbonate (CaCO3) powder is used
- 40 g of CaCO3 are distributed across each module test specimen per sand event
- 1 sand event every 16 cleaning cycles
- Final characterization after approximately
    - 3900 cycles or equivalent to 25 years of 3 cleanings per week
- Cleaning Brush: Hahl Poyester PBT, colour B3/3-dark blue.

4. 2. Test Specimen

For the accelerated testing, three glass-backsheet modules of the type GCL-P6/72H330 from the manufacturer GCL Solar were used which were provided directly by the Customer. This is a framed module type with 72 cells.

4. 3. Operating Principle of Solaris Hydrobotics Robot

Solaris Hydrobotics Robot is a water powered cleaning device consisting of three components the driving cart, the brush & connecting rods and the secondary cart and moves directly on top of the module's frame. The part of the wheel in contact with the module is a

tire made of synthetic rubber blend, made of butadiene + SBR + NR (Natural Rubber) with a hardness of 60 Shore A.

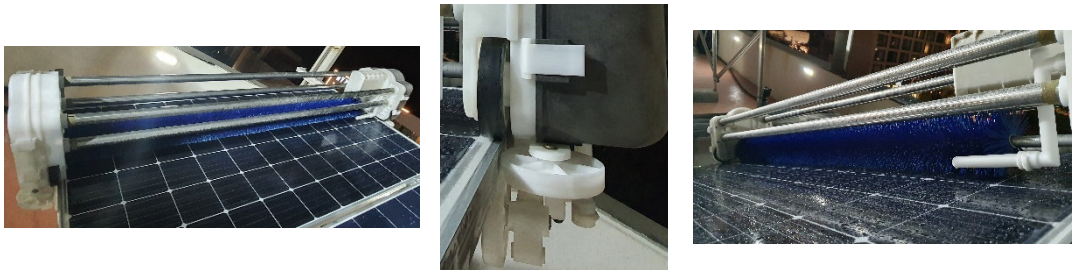


Figure 4-1: views of robot: general view (left), wheel (middle), cleaning brush (right)

4. 4. Test Set-up

The test specimens were mounted horizontally (Figure 4-2). The third module mounted on similar test rack in a similar environment was used as a control module (Figure 4-3), no cleaning and no sand event.

Figure 4-2: Test setup, cleaning robot in parking position and test modules mounted. The left and right modules of this group of four are the parking positions for the robot. The test modules are the two middle ones.

Figure 4-3: Reference module, isolated from the other ones.

4. 5. Testing Sequences

Initially, all modules undergo the same stabilization process (in accordance with IEC 61215:2016-03 MQT 19.1) so that they are electrically stabilized for the measurements. After that, all three modules are subjected to initial characterization. For the cleaning simulation, two modules were subjected to soiling and cleaning, while one was kept as a reference.

#	Module type	Serial number (module supplier)	Internal number (PI Berlin)	Description	# of cleanings	# sand events	Intervals
1	GCL-P6/72H330	271904168260513	2021070078	25 years cleaning (3 cleaning per week)	3900	250	16
2	GCL-P6/72H330	271904168260666	2021070080	25 years cleaning (3 cleaning per week)	3900	250	16
3	GCL-P6/72H330	271904153200856	2021070079	Control module – no cleaning at all	-	-	-

4. 6. Test Description & Evaluation Criteria

Detailed information about the test descriptions "Visual Inspection", "I-V Curve Determination at STC", "Electroluminescence Analysis" and "Reflectance Measurement" can be found in Section 3.1 of the laboratory report G2021129La_V1 which is provided as an Appendix.

In addition to the "Visual Inspection" according to IEC 61215-2-2016 Section 10.1 a second type of visual inspection was also performed in order to better visualize the change of reflection/gloss. For this purpose the test specimens were tilted to receive a reflection of the lamps directly on the surface. Another tool to visualize the impact of the cleaning procedure was an adjustment of the image settings afterwards. Any image adjustments will be clearly stated in the analysis.

There is currently no international standard to classify the impact of a cleaning procedures on PV modules. No evaluation criteria were communicated nor agreed for this assessment. The following report will therefore only summarize the findings without acceptance/rejection criteria.

5. Test Results

In this section, the relevant test results will be merged to present an overall summary of the results. The detailed listing of the measurement results can be found in the laboratory report G202129La_V1 in section 4. The specific passage in the laboratory report will be referenced when necessary.

5. 1. Visual inspection

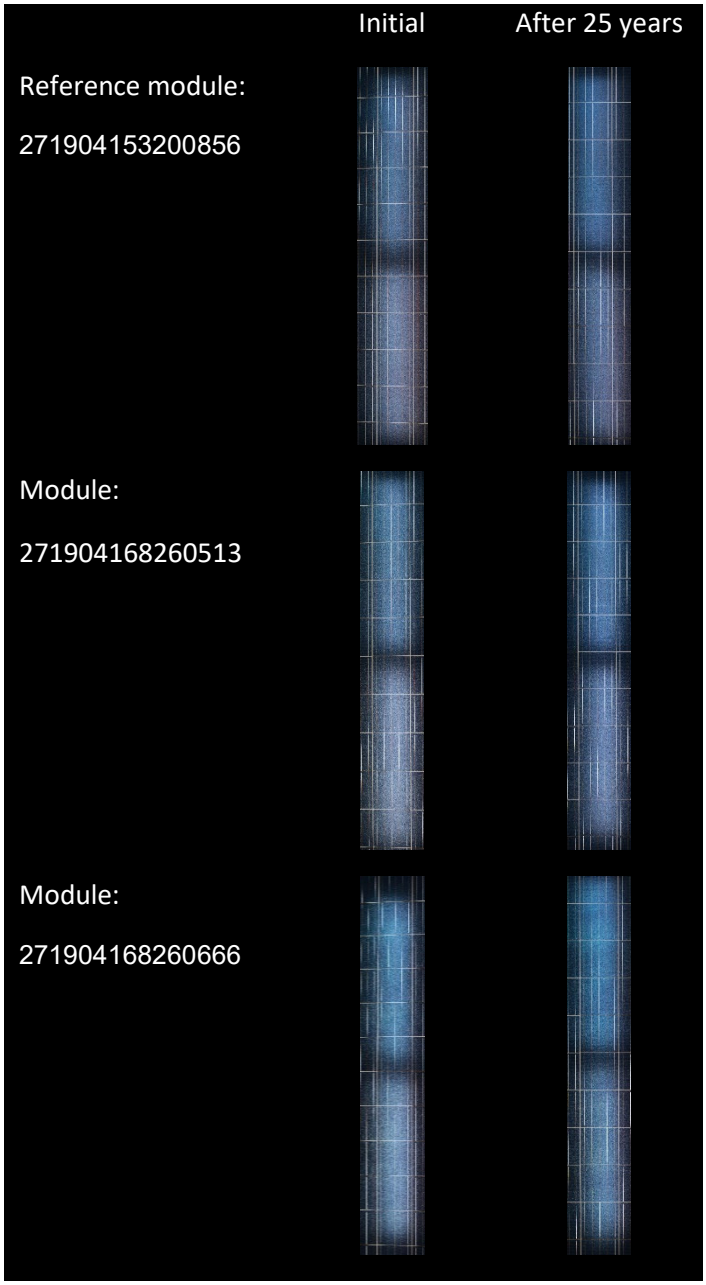


Figure 5-1: Overall comparison of all VI images (lamps reflecting on modules)

All results of the visual inspection, summarized in figure above, and detailed in the attached laboratory report G2021129La_V1, show the following effect of the cleaning robot on the glass surface:

- No major defect is visible after cleaning;
- Direct comparison (Figure 5-1) does not show a general degradation of ARC-coating by changing reflection colour, i.e. colour change or increasing reflection intensity;

- Minor marks, most likely scratches are visible after cleaning. They are visible only when inspection lamps are reflecting on the modules, suggesting that they are superficial.

5. 2. Performance at STC

Figure shows the gathered performance results of the test specimen over the whole test period. The error indicators represent the repeatability error (0.33% on Pmax) of the measuring equipment.

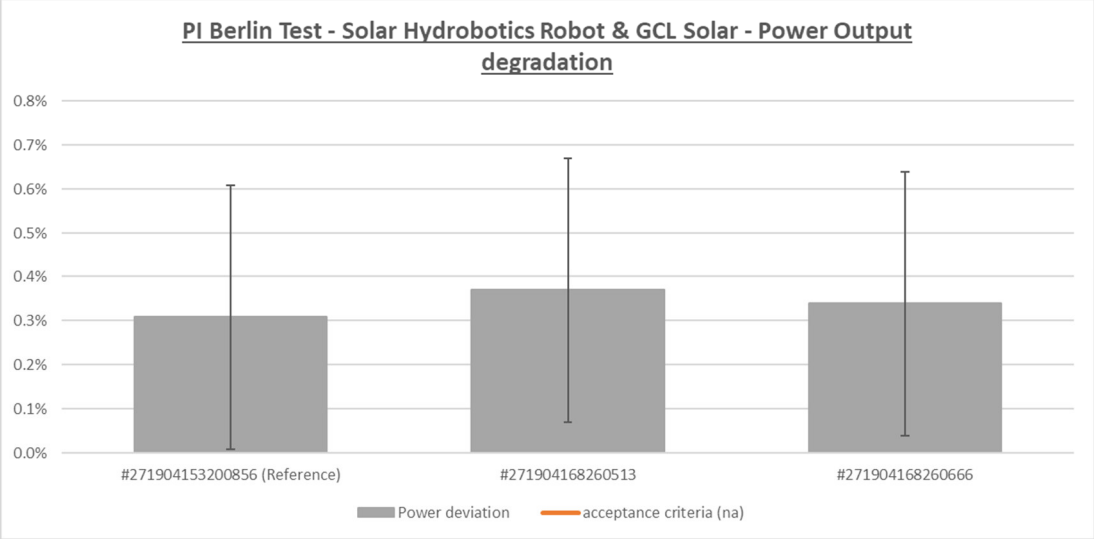


Figure 5-2: Power output deviations to the initial characterization of all test modules

The tables below present the STC measurement test results of the test specimen over the whole test period, including the reference module.

Serial Number	Status	PMPP (W)	VMPP (V)	IMPP (A)	VOC (V)	ISC (A)	FF (%)	Power deviation
Label		330.00	37.80	8.73	46.20	9.33	-	-
#271904153200856 (Reference)	Initial	324.7	37.78	8.6	45.69	9.09	78.2	
years of daily cleaning / # cycles	Final	325.7	37.62	8.66	45.75	9.12	78.1	0.3%
#271904168260513	Initial	323.8	37.73	8.58	45.63	9.08	78.1	
years of cleaning / # cycles	25/3900	325	37.61	8.64	45.7	9.11	78.1	0.4%
#271904168260666	Initial	324	37.5	8.64	45.6	9.1	78.1	
years of cleaning / # cycles	25/3900	325.1	37.75	8.61	45.68	9.11	78.1	0.3%

The following points summarize the results:

- No noticeable degradation is measured neither on Pmax nor Isc.

5. 3. Electroluminescence

The presented EL-results in section 4.1 in the laboratory report G2021129La_V1 and bellow have clearly shown that:

- None of the test specimen has shown any recognizable changes of the cells, after a test duration up to 25 simulated years; and
- The cleaning robot, as tested in the presented set up (see chapters 4. 3. and 4. 4.) has absolutely no negative mechanical influence on this type of PV module.

#271904153200856 (Reference)

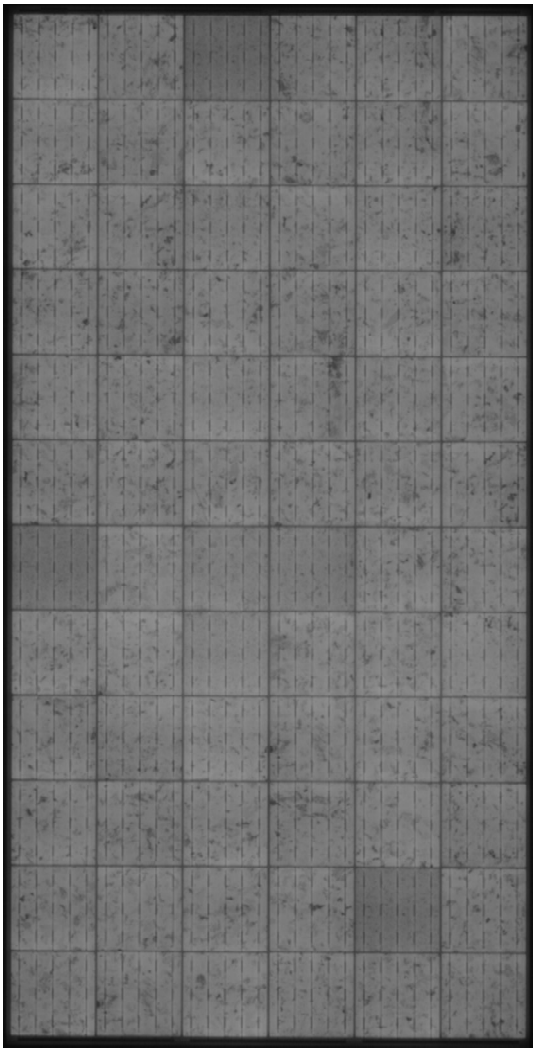


Figure 5-3: Initial

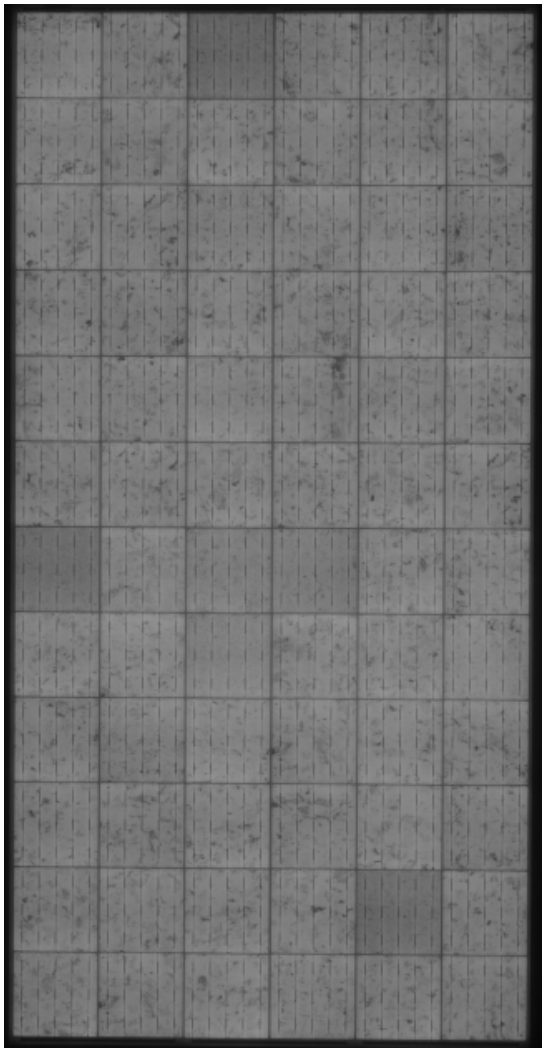


Figure 5-4: After Cleaning

#271904168260513

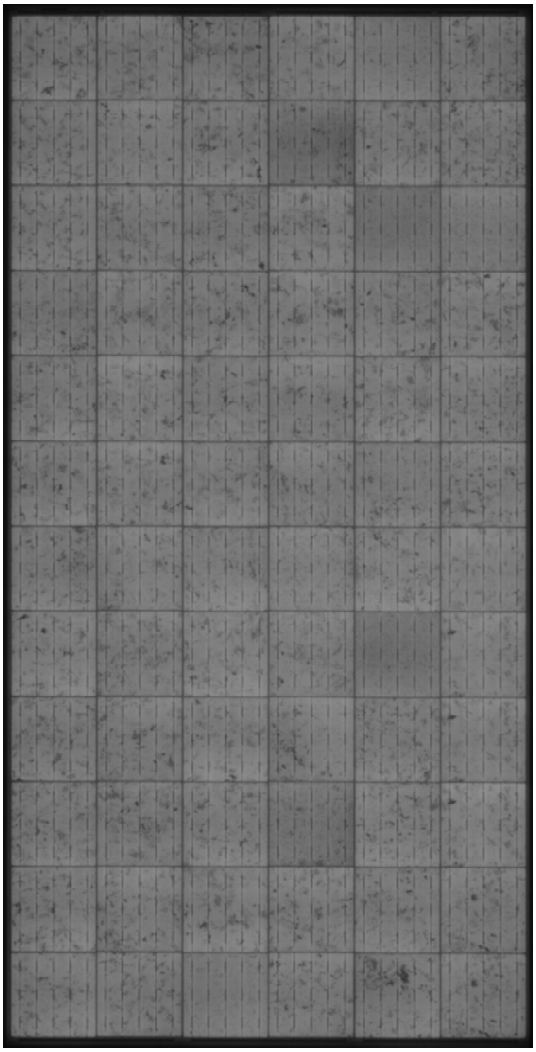


Figure 5-5: Initial

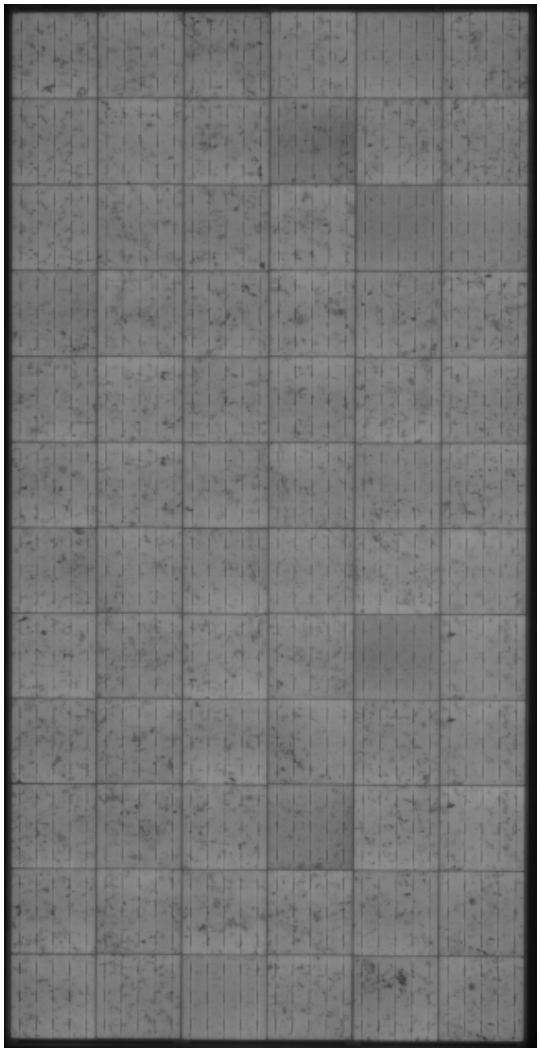


Figure 5-6: After Cleaning

#271904168260666

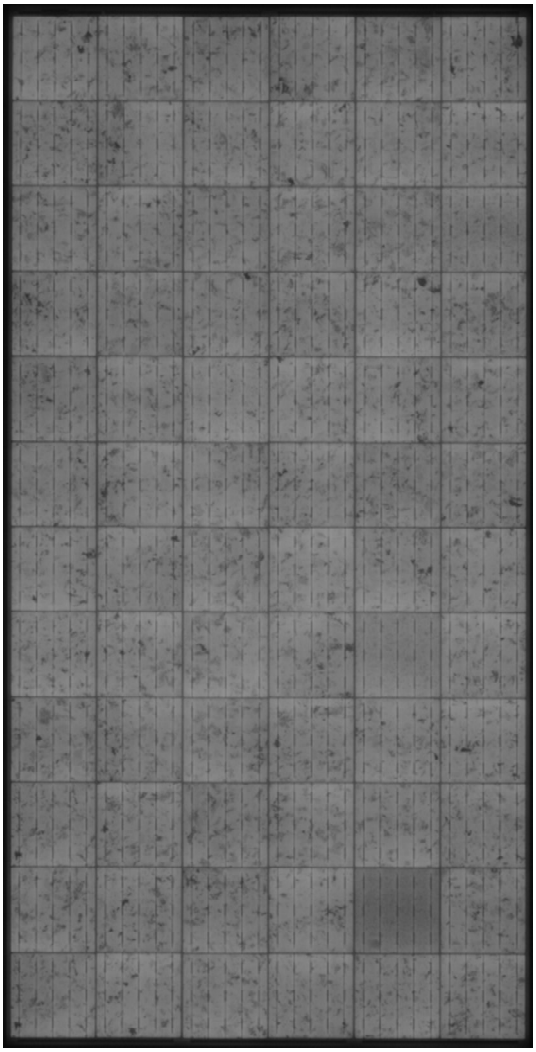


Figure 5-7: Initial

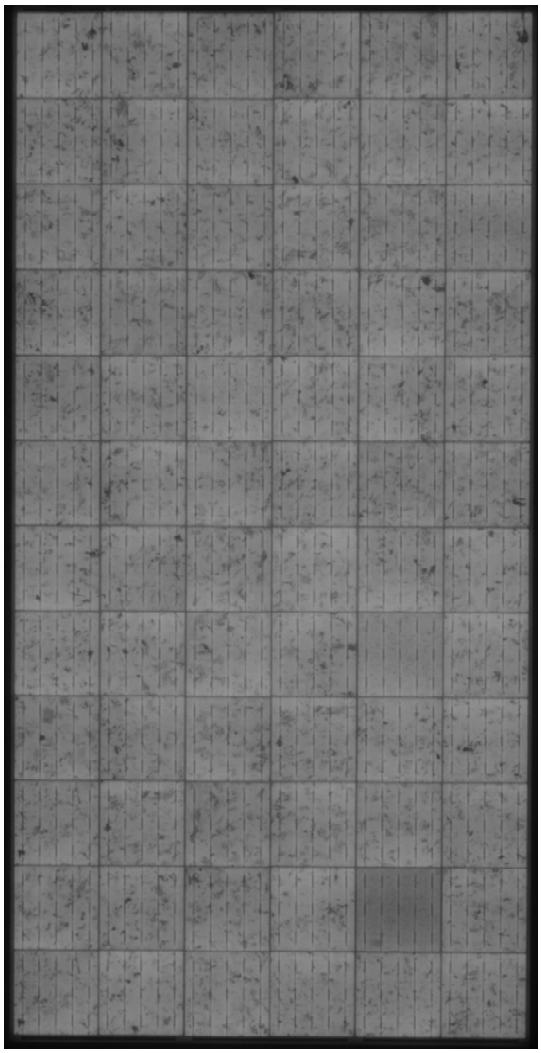


Figure 5-8: After Cleaning(Cust)

5. 4. Reflectance measurements

Figure 5-9 shows the average of the reflectance, measured at 6 different positions of the test modules over the whole test period (initial and final characterization) While the **Error! Reference source not found.**Figure 5-10 how the details of the 6 different positions, initial and final characterization.

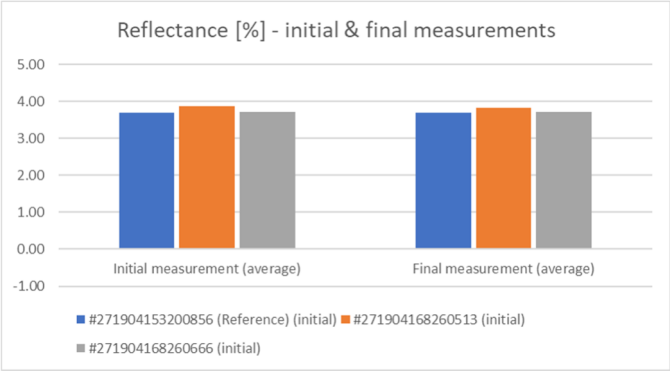


Figure 5-9: Reflectance [%] - initial & final measurements - average

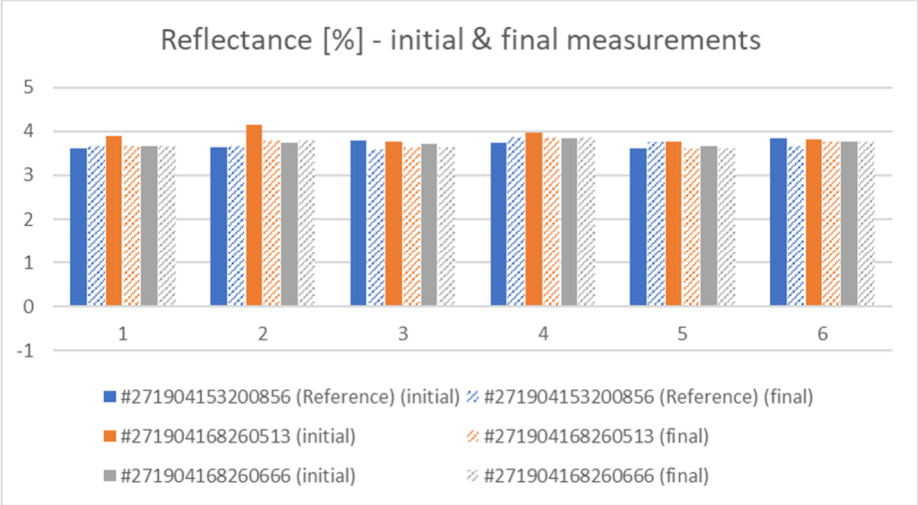


Figure 5-10: Reflectance [%] - initial & final measurements – details

6. Conclusions

This report evaluates the impact on a specific PV module of the automatic cleaning device from Solaris Hydrobotics applied three times per week over 25-year periods. The laboratory tests were conducted on a PV module from the supplier GCL Solar of the GCL-P6/72H330.

An amount of 40 g of CaCO3 powder was distributed across each module test specimen per sand event every 16 cleaning cycles. Final measurements conducted after completion of cleaning simulation do no reveal noticeable negative impact of the Solaris Hydrobotics cleaning solution on the tested modules applying the test protocol describe in section 4 of the current report.