New solar PV panel renovation/repair technologies for demanding climate using polysiloxane

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The challenge

- First tier (bankable) PV panel manufacturers declare PV panel lifetime 25-30 years, workmanship warranty 12-30 years.

- **Real field lifetime of new PV panels, till critical reduction of PV panels WET Risol (ground impedance), is about 3-12 years namely in tropical climate (India, MENA…)**

- Commercial leaflets declare PV panel degradation rate is 0.4-0.6% per year

- Laboratory tested DRY panels degradation rate is typically **0.9 - 4.9%** in tropical climate

- Real field Risol of WET (morning/rain) PV panels is about 1000x reduced compared to DRY panels at laboratory tests

The reason

Fast reduction of insulation resistance Risol (ground impedance) is observed after 3-4 years in tropical climate. Degradation of polymer back sheet laminate as well. Other damages like delamination too.

These facts are supported by monitoring of 100s PV power plants worldwide. Risol degradation is faster at tropical climate.

[1] Poulek et al. IEEE Journal of Photovoltaics, vol. 11, no. 2, pp. 561-565, March 2021, doi:10.1109/JPHOTOV.2021.3050984 https://ieeexplore.ieee.org/document/9339850 download link

[2] Kim et al. Energies, 2021, 14, 4278 https://www.mdpi.com/1996-1073/14/14/4278

[3] Buerhop-Lutz at all, Solar Energy Materials & Solar Cells 231 (2021), https://doi.org/10.1016/j.solmat.2021.111295

[4] Voronko et al. Energy science,2021, https://doi.org/10.1002/ese3.936

Degradation of usual design glass/TPT c-Si PV panels in demanding climate

Location Reference	Senegal [5]	Ghana [6]	India [7]	Morocco [8]	India [9]	Thailand [10]	Algeria [11]
Annual degradation	2.96%	3.19%	2.5%	2.6%	20%	2.7%	2.6%
Outdoor exposure	**4 years**	12 years	10 years	**3 years**	**2.5 years**	**3 years**	11 years

[5] Atsu D. *at al*, Renewable Energy 162 (2020) 285e295

[6] Ababacar N. *at al*, Solar Energy 103 (2014) 70–77

[7] Sastry O.S., *at al*., Solar Energy Materials & Solar Cells 94 (2010) 1463–1468

[8] Bouaichi A. *at al*,. Renewable Energy 143 (2019) 1500e1518

[9] Sharma V. *at al*, Solar Energy 134 (2016) 32–44.

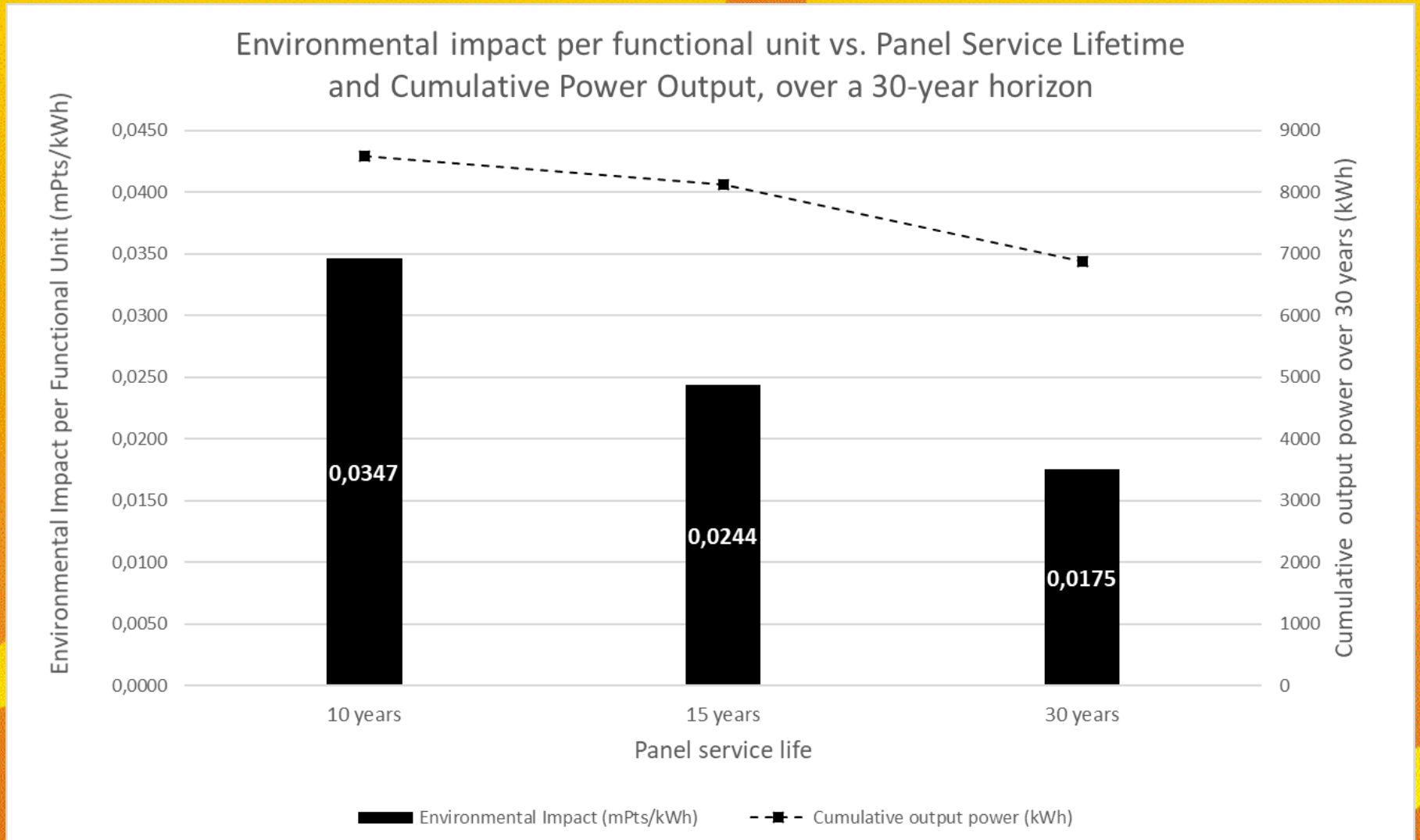
[10] Le N.R. *at al*, IEEE Access 9(2021).

[11] Bouraiou A. *et. al*,, Energy Conversion and Management 106 (2015) 1345–1355

There are more degradation reports but it cannot be published because after PV power plant early failure the data are usually declared confidential. Typical example is fast degradation of 86MW PV power plant in South Africa. Just **3.5 years** after PV power plant opening there was substantial output power reduction because of PV panel back sheet degradation. The exact data are confidential [12].

[12] Heubl B., Millions of solar PV panels could fail or degrade prematurely and may even be at risk of fires. But no one knows exactly where they are or how big the problem is, *Engineering & Technology*, vol. 15, no. 9, pp. 38-41, Oct. 2020, doi: 10.1049/et.2020.0904.

International Energy Agency, IEA PVPS report, https://iea-pvps.org/wp-content/uploads/2021/11/IEA_PVPS_T12_Preliminary-EnvEcon-Analysis-of-module-reuse_2021_report_slides_summary.pdf. 2021, pp.30-34.



Within last 15 years price of PV panels was reduced about 13 times

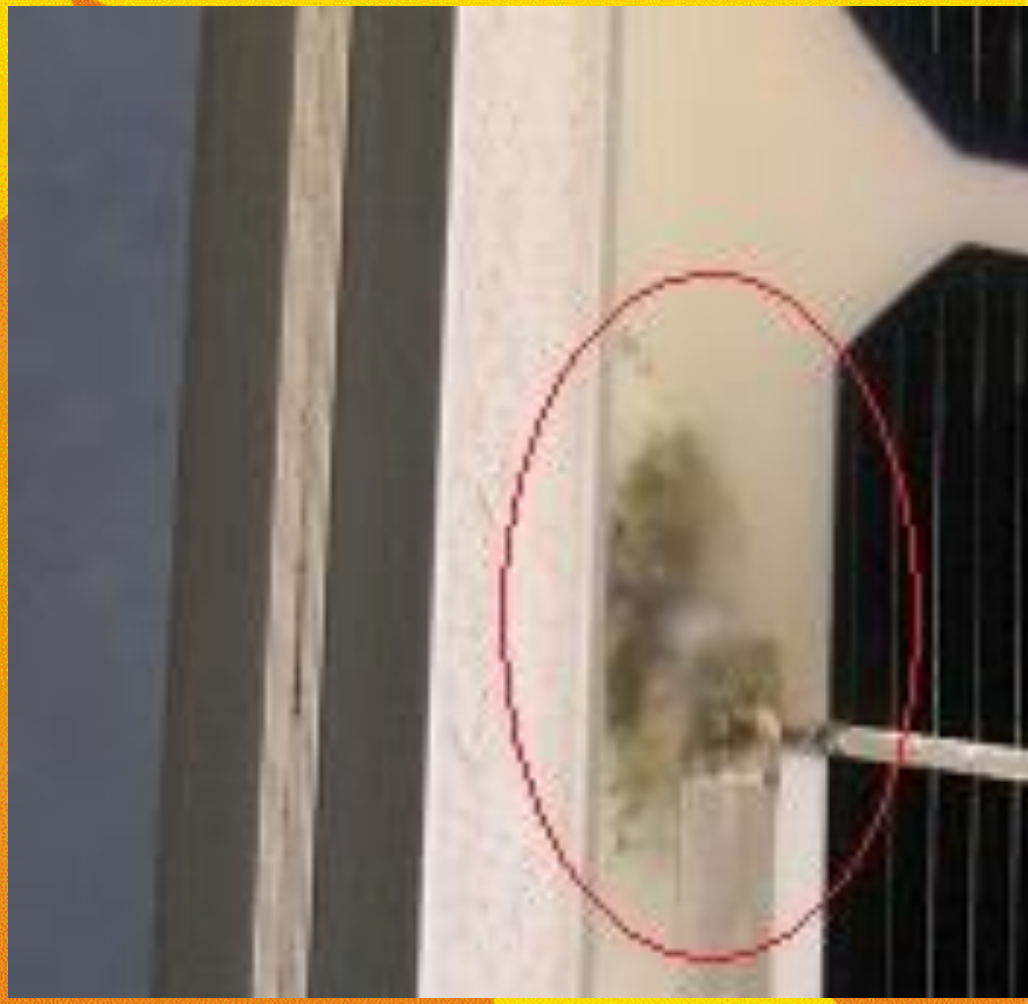
The quality of first tier (bankable) PV panels has been reduced too

Material of the PV panel back sheet was changed from top quality PVF (Tedlar) to lower quality plastics like PET, PP…..

PV array system voltage was increased from 600-800VDC to 1200-1500VDC. As the new system voltage is double the leakage current is double too (Ohms law). But the leakage current power is $P = R*I^2$
So the leakage current (degradation) power is increased 4 times.

The newer is the PV panel the higher is the degradation rate.

The PV panel electric breakthrough (see photo) caused by reduced Risol is usually destroying soon the inverter which is more expensive than the PV panel itself. As the single damaged panel can either switch of or damage the multi string inverter servicing **STRING** of 10s of PV panels, such failure have **MULTIPLICATION EFFECT.**



Usual/typical degradation steps are as follows – 5th year

Risol (ground impedance) typically about 500Mohm

Visual appearance – invisible. Touching the back sheet TPT by hand, white powder adhere to fingers - “chalking”. See photo below

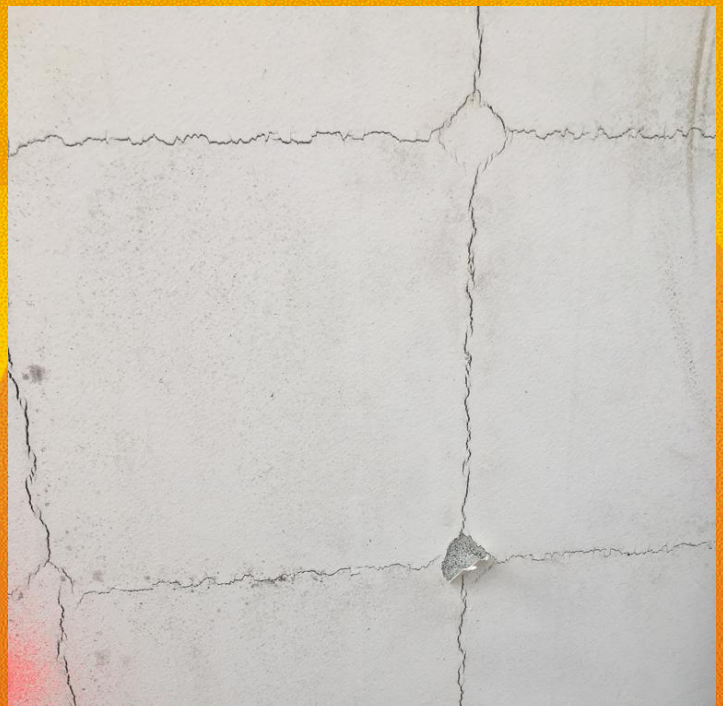
Typical renovation/recycling (consumables) cost 6 USD per 440Wpanel (size 1x2m). GW volume.

6th year

Risol (ground impedance) typically about 100Mohm

Visual appearance – large cracks at the back sheet TPT See photo below

Typical consumables cost 6 USD per 440W panel (GW volume)

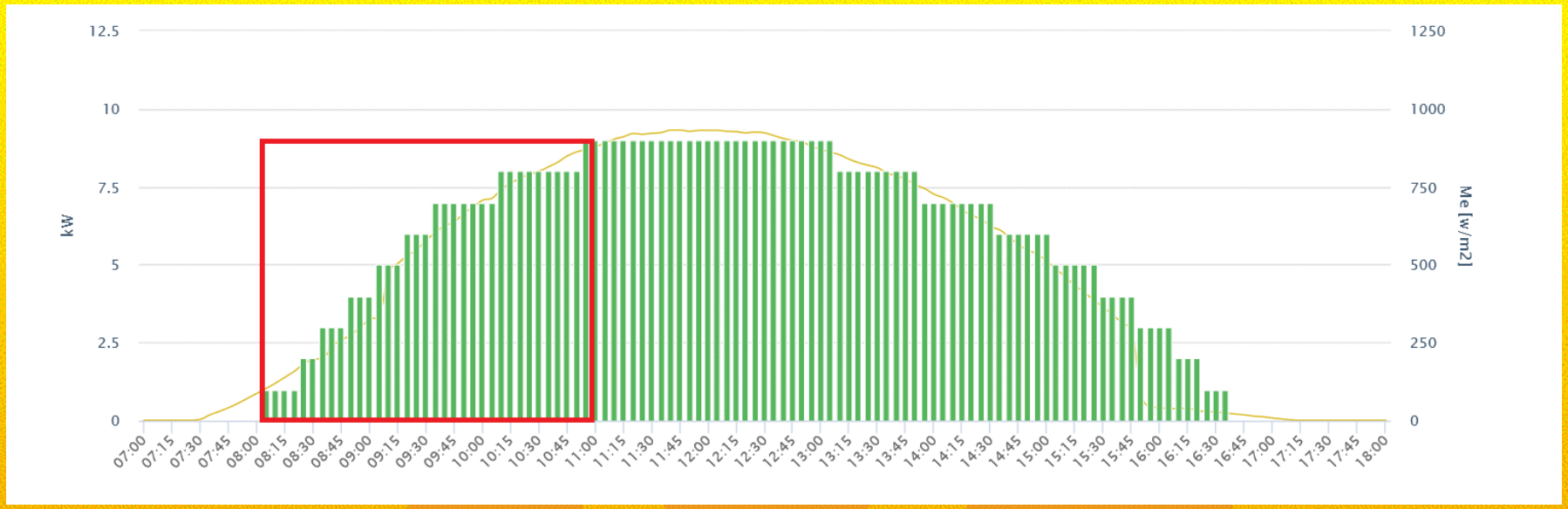


7th year

Risol (ground impedance) typically below 25Mohm

Visual appearance – discharge channel between busbar and the grounded frame. See photo below (bottom-centre)

Typical renovation/repair cost 47USD per panel



PV panels with damaged TPT have 1000 times reduced Risol in the morning until the surface water is dried off. It takes about 3 hours till Risol is restored. Substantial part of the energy produced by PV panels in the morning is lost because the inverters are not connected to the grid (because of low Risol is detected) just after sunrise .

Another methods of PV panel renovation/repair

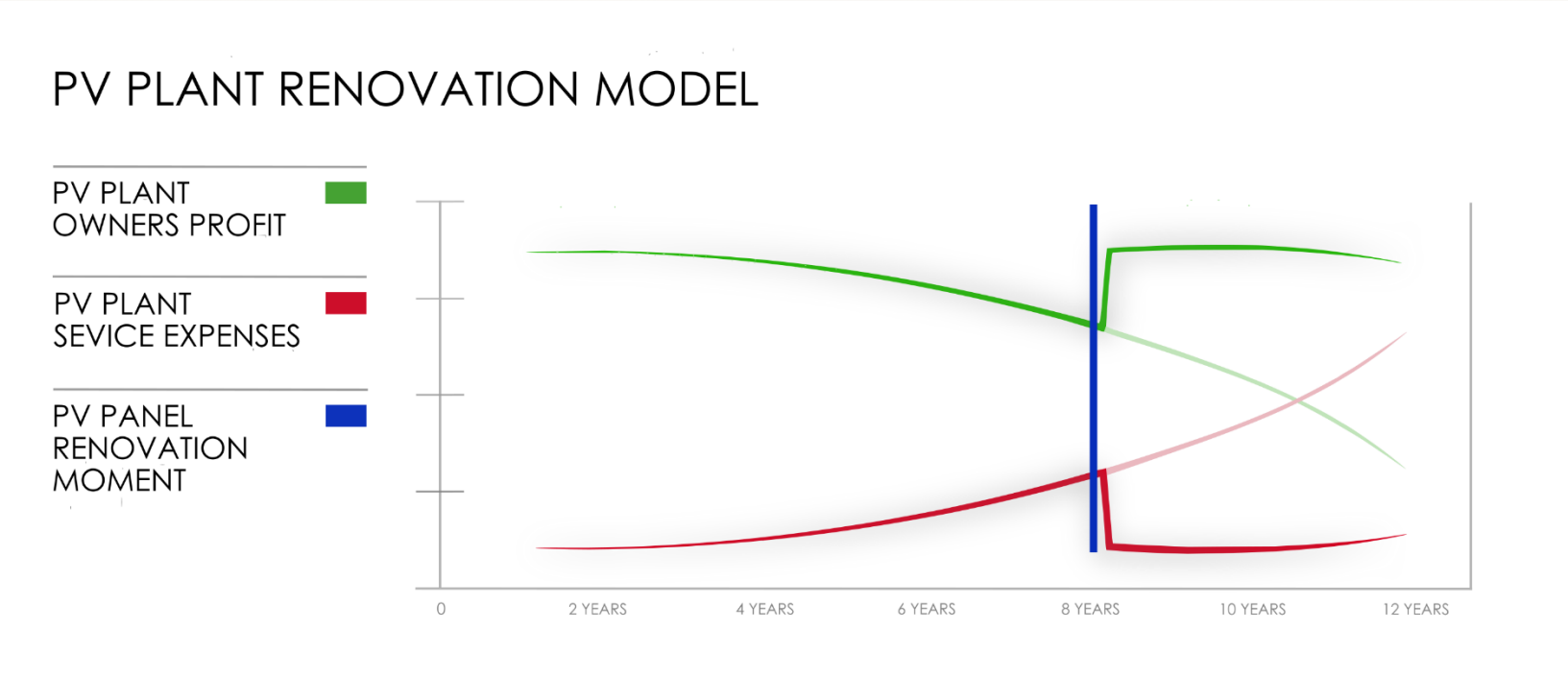
There are other more expensive and less reliable methods of PV panel renovation/repair.

Typically whatever cheap paints were tested but reliability/lifetime was low.

There were also efforts with cheap additional polymer films or laminates but on site application was difficult and reliability was low (delamination etc..)

Servicing expenses

PV power plant servicing companies usually prefer substantially more expensive panel replacement to PV panel renovation/repair. The motivation of PV power plant owners is just oposite.



The solution
A) PV panel renovation/repair

Usual replacing of degraded/damaged PV panels by new ones is very expensive method. Aditionally carbon footprint of this method is extremely high.

New method of fast on-site low-cost renovation of PV panels using siloxane film was developed. It is approximately 11 times less expensive compared to PV panel replacement. Result of renovation is complete recovery of PV panel properties including isolation resistance Risol.

PV panel renovation/repair process

Complete damage check (Risol….)

Timing (daytime, yearly seasons)

Cleaning (dry, wet)

Renovation method –back sheet film deposition, painting…)

Renovation material – siloxane….

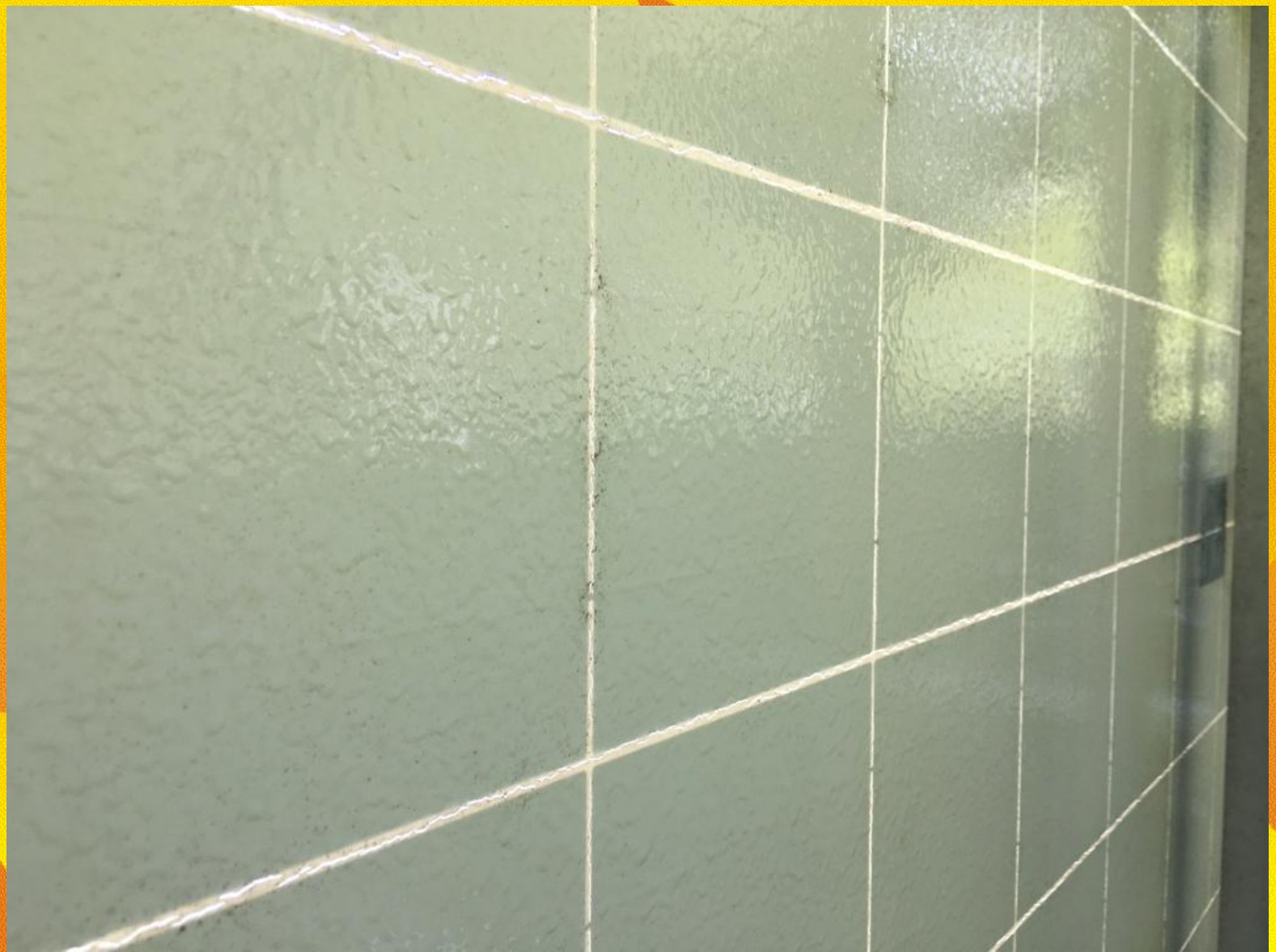
Renovation film properties (film thickness, uniformity….)

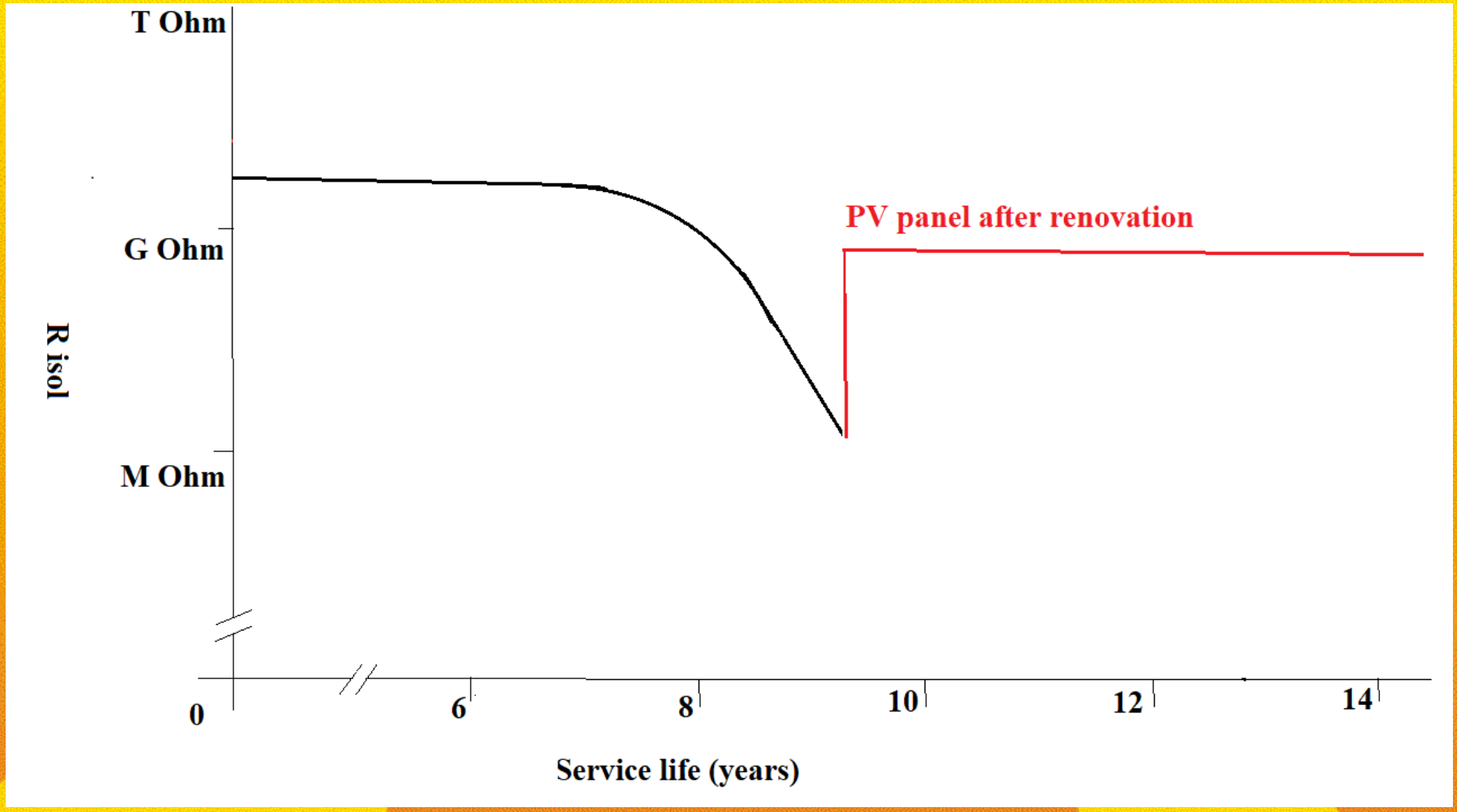
Final after renovation check (Risol….)

Verification check after 5 years

Low cost renovation can be performed repeatedly

PV panel back side after siloxane film application





Ground impedance (Risol) before and after PV panel renovation

PV panel renovation equipment at 3MW PV power plant

Improved back sheet abrasion resistance

Additional back sheet layer results in improved sand/soil abrasion resistance

References

Since year 2018 siloxane gel renovation/repair was performed on 17 PV power plants. Total PV plant capacity has been 41MW on November 2022

The carbon footprint

The carbon footprint is increasingly becoming an important criterion. We can compare the carbon footprint of a new replacement PV panel with the carbon footprint of the PDMS renovation film as follows:

a) The manufacturing carbon footprint of a typical first-tier (bankable) PV panel, sized 1 x 1.6 m and with a power output of 360W (weighing approximately 20kg), results in 120 kg CO2 eq.
b) b) The manufacturing carbon footprint of a typical 0.1mm thin polydimethylsiloxane film, sized 1 x 1.6m (weighing 0.15kg), results in 0.94 CO2 eq.

The replacement/renovation carbon footprint ratio is 121 to 1, and the replacement/renovation weight ratio is 133 to 1 (see Table 2). PV panel renovation is also significantly less expensive compared to PV panel replacement, with a replacement/renovation cost ratio of 11 to 1. Please refer to Table 2 for more details.

Table 2. PV panel replacement and renovation comparison (size 1x1.6m, power 360W

	Weight of replacement/renovation item	Carbon footprint of replacement/renovation item	Estimated lifetime of replacement/renovation item	Replacement/renovation cost (material, labor, transport….)
PV panel replacement by new one	**20kg**	**~120kg CO2eq**	**About 7-10 years**	**~120 USD**
PV panel renovation by PDMS film	**0.15kg**	**~0.94kg CO2eq**	**About 5-7 years**	**~11 USD**

The advantage

Low cost consumables 6 USD (440W panel 1x2m) GW order

On-site: No PV panels disassembly from the support rack

Pay back time about ~6 months

PV power plant renovation cost is ~5% of total plant cost

Low cost PV panel renovation can be performed repeatedly

Prevents complete damage of inveters (multiplication effect)

PV panel life extension ~ +50%, carbon footprint +0,3%

Fast renovation- 4 minutes per panel

Improved back sheet abrasion resistance

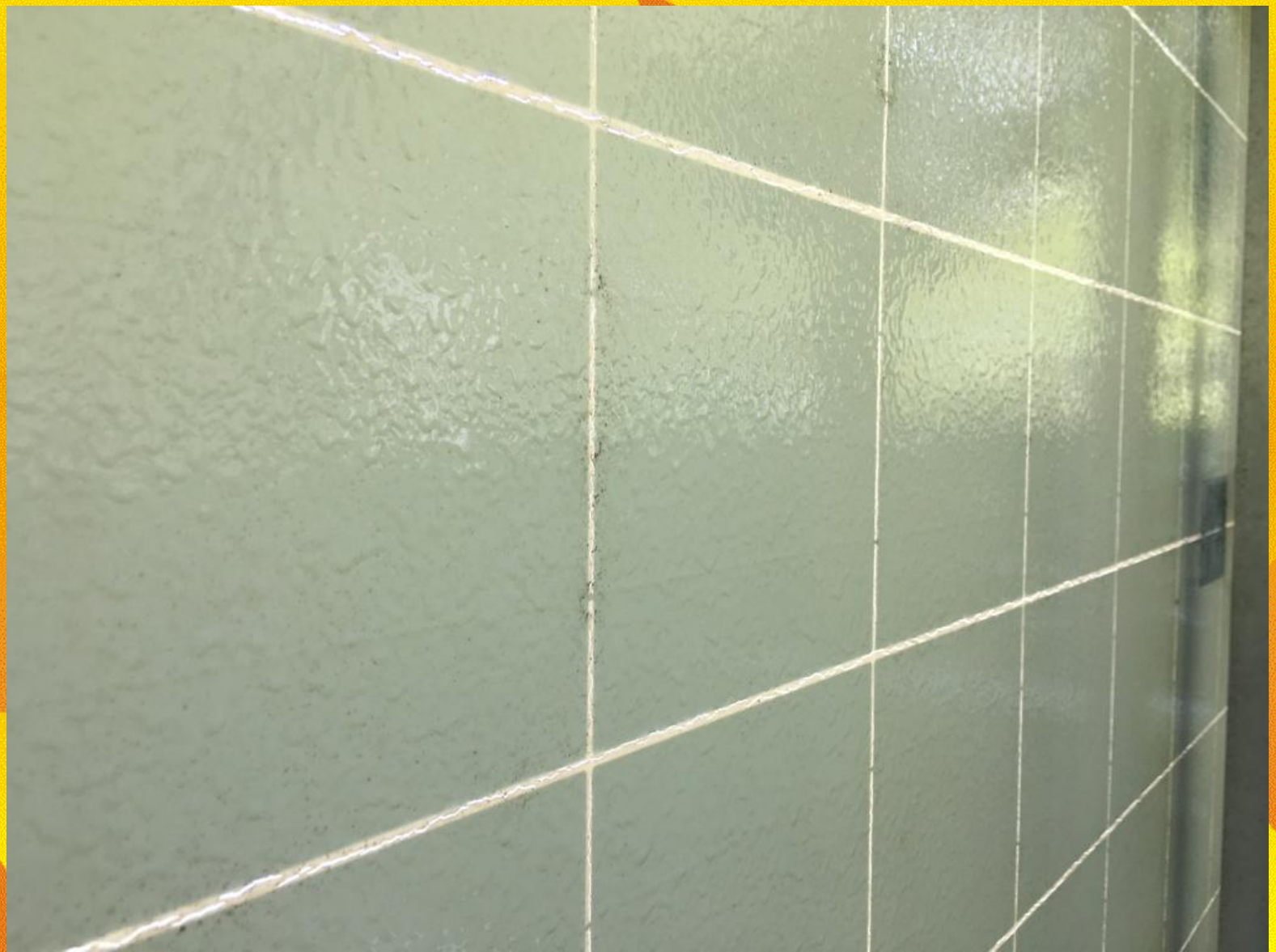
The solution

B) PV panel upgrade technology

New method of upgrade of PV panels at manufacturing line using siloxane film was developed.

PV panel price increase is 5% only. REAL lifetime of PV panel is prolonged for more than 30%

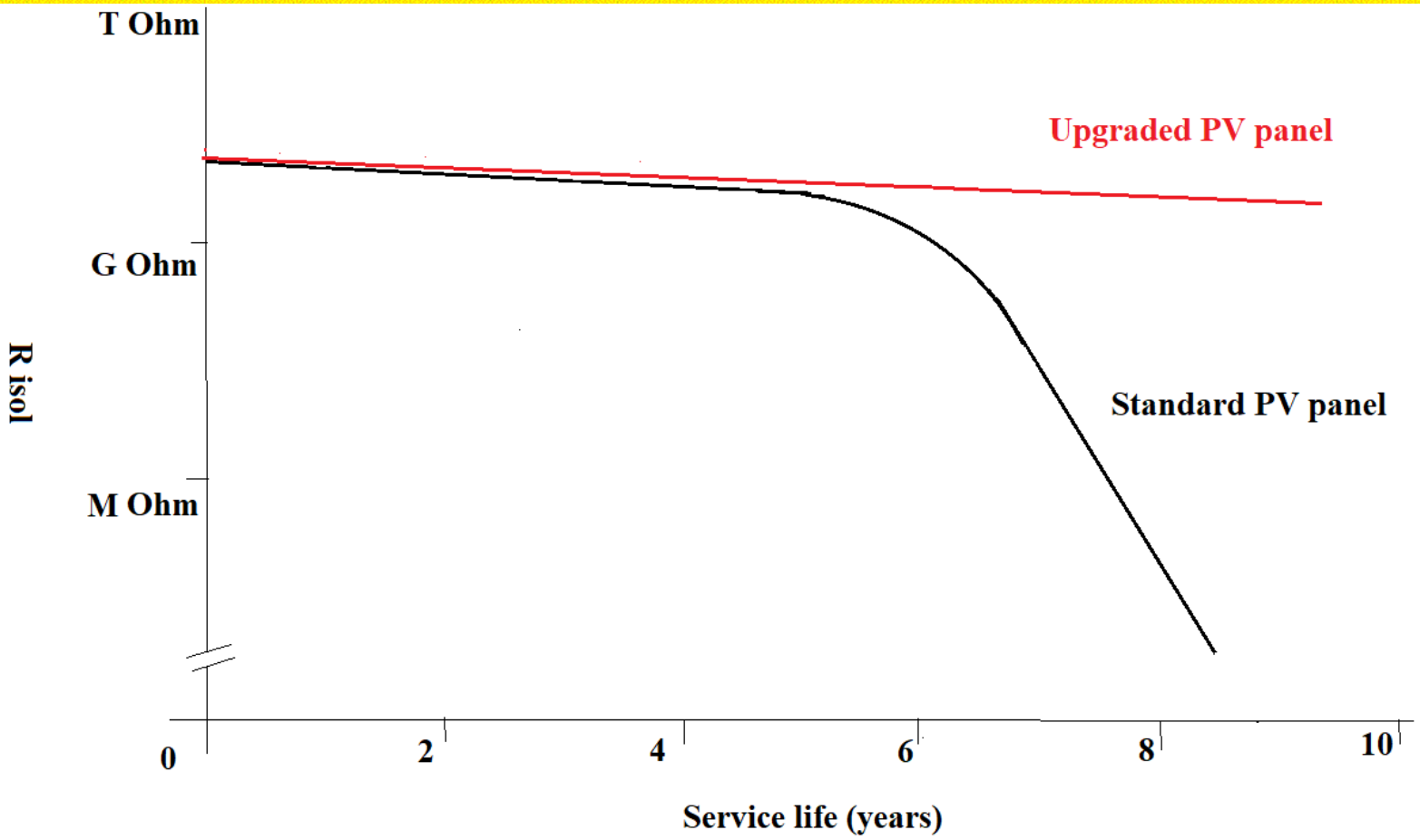
PV panel back side after siloxane film application



There are two possible arrangements

1) In-line automatic protective layer deposition where the layer application machine is included into the PV panel production line (before framing machine).

2) Automatic application of the protective layer on the back side of the finished new PV panels (out of the PV panel production line)



Comparison between standard and upgraded PV panel early morning (wet) insulation resistance

PV panel upgrade can increase REAL lifetime by about 5 years

The solution

C) New PV panel lamination/production technology

Under same condition, the most effective method to increase the economic competitiveness of Solar Panel is to increase its lifetime.

The main factor determining the operational lifetime of solar panel is its encapsulant.

Unlike solar cells the recent encapsulant (EVA) was not improved within last 30 years

The corrosiveness of recent EVA encapsulant for solar cells and interconnect break are the main sources of solar panel failures (i.e. reduced lifetime). Tab.1 gives the main source of solar panel failures

Tab.1 the main source of solar panel failures:

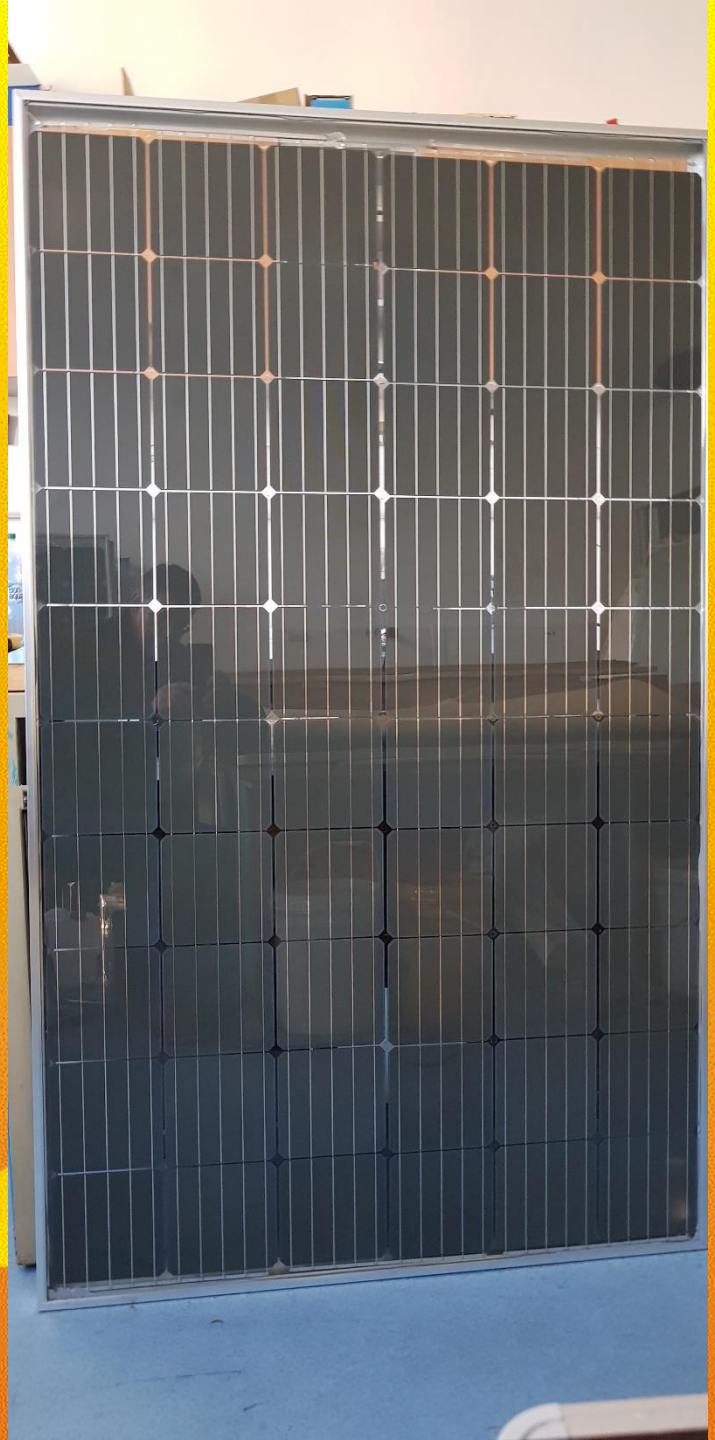
Type of failure	total failures (%)
Corrosion	45.3
cell or interconnect break	40.7
output lead problem	3.9
J-box problem	3.6
delamintion	3.4
overheated wirs or diodes	1.5
mechanical damage	1.4
defective bypass diodes	0.2

New encapsulant material, silicon gel, for solar panel

Development of materials with high light and thermal stability for use in solar panels is urgently need

From standpoint of optical transparency, operational temperature range and absence of corrosive impurities (e.g., acetic acid in EVA), silicon gel is the most attractive candidates.

polysiloxanes have been proved and used for decades as adhesive and sealing materials for space solar cell at extreme temperature range from -115^{o}C up to +150^{o}C.



PV panel laminated by polysiloxane

Advantages of silicon gel

- Inert and hydrophobic material
- Temperature resistant material -55^{o}C ~ +250^{o}C
- Highly transparent material
- Low production energy consumption
- Environmental safety

Tab.2 comparison of EVA and siloxane gel properties

	EVA	Siloxane gel
long term operational temperature	**-40℃, +80℃**	**-55℃, +150℃**
UV radiation resistance	low	high
operationnal life time	20-30 years (5-9 years real)	50 years real
long term annual degradation	**0.8%-4.9%**	**0.15%-0.22%**
refractive index	1.482	1.406
transparency for solar radiation 360nm	8%	90%
transparency for solar radiation 400nm	62%	92%
transparency for solar radiation 1000nm	91%	93%
corrosive agent-lamination	acetic acid	none
corrosive agent-agening	acetic acid	none
mechanical stress-lamination	yes	none
mechanical stress-ageing	yes	none
Solar concentrator (500X) application	NO	YES
Space (satellite) applications	NO	YES

Advantage of Silicon gel Encapsulanted Solar Panel

PV panel load test at -55°C

- Operating temperature -55 °C to 115°C
- Glass-Glass solution for bifacial technology
- lifetime up to 50 years
- Eliminates over 80% of standard panel failures.
- Panels are fireproof

Tab.3 Specification of Silicon gel encapsulated Solar Panel

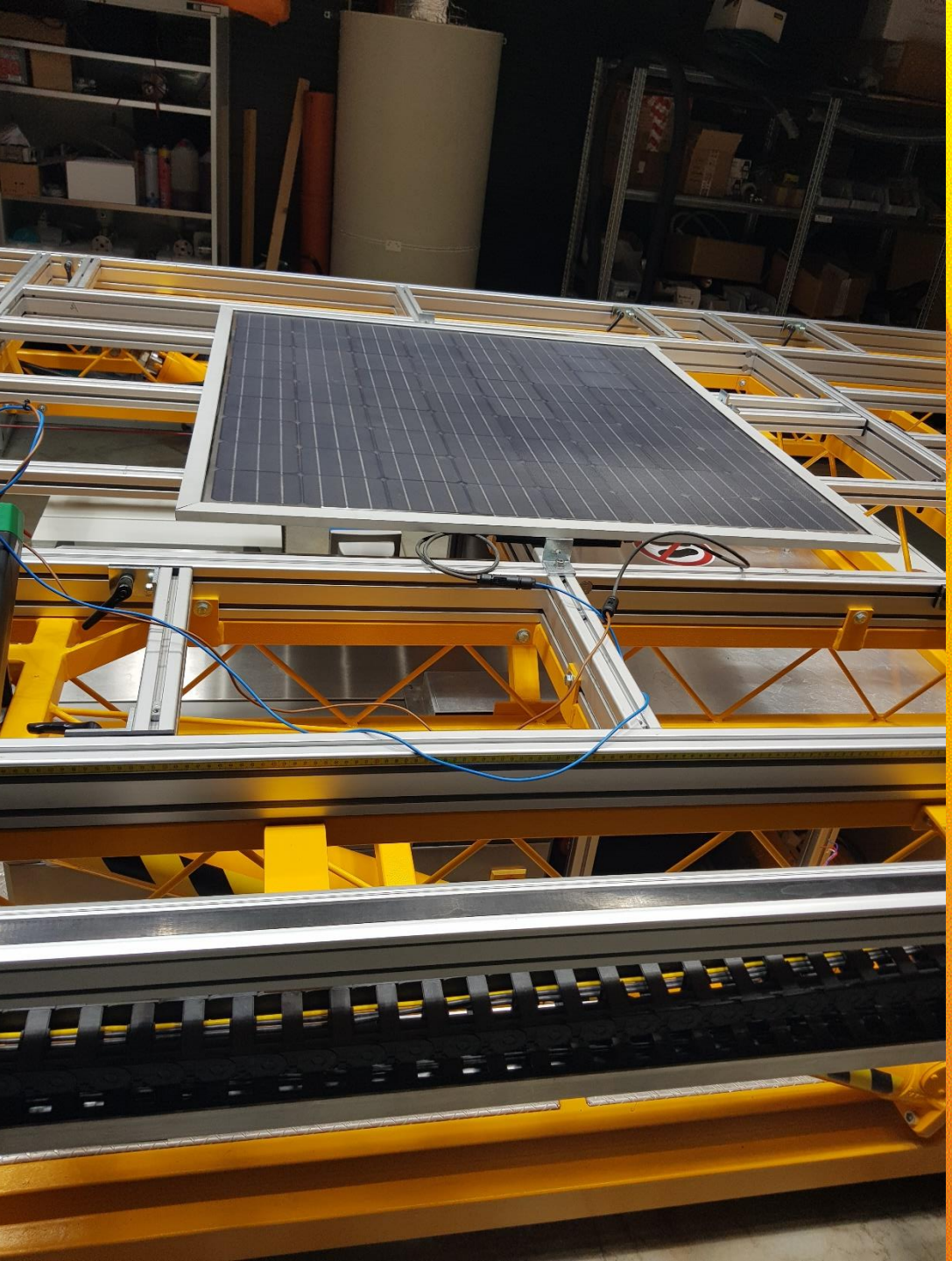
Maximum Power at STC（Pmax）	610W
Maximum Power Voltage（Vmp）	50,12V
Maximum Power Current （Imp）	12,18
Open Circuit Voltage(Voc)	59,95V
Short Circuit Current（Isc）	13,21A
Module Efficiency	19.3%
Operating Module Temperature	-55℃ to +115℃
Maximum System Voltage	1.500V
Maximum System Fuse Rating	20A
Power Tolerance	0/+5W
Nominal Operating Cell Temperature NOCT	45 +/- 2°C
Temperature coefficient of the Isc	0.06%/°C
Temperature coefficient of the Voc	-0.34%°C
Temperature coefficient of the Pmax	-0.40%/°C
Solar Cells	Mono Si, 6 Inches
Dimension(AxBxC)	1998x1312x40mm
Weight	45kg (glass/glass)

Evaluation of panels laminated by silicone gel

Evaluation of TRAXLE panels after 12 years outdoor exposure at Czech University of life sciences in Prague show degradation 0.2% per year.

Tab. 4 Long term degradation of siloxane laminated PV panels at moderate climate

Location	PV panels supplier	Siloxane manufacturer	PV laminate	Si cells	Evaluation period	Annual degradation
USA, MD	Solarex/BP Solar	USA	Glass/polymer	poly	1982-2008 (26 years)	0.21%
Japan, Nara	Sharp	Japan	Glass/polymer	mono	1983- 2012 (29 years)	022%
Czech, Prague	Traxle	Russia	Glass/glass	mono	2008-2023 (15 years)	0.21%
Ispra, Italy	Arco	USA	Glass/glass	mono	1984-2014 (30 years)	0.15%



Gel laminated panel on xenon lamp test

Evaluations

Sharp and BP solar panels laminated by silicon (same materials but very expensive and very difficult lamination technology) after outdoor testing for 29 and 26 years show 0.21-0.22 degradation according to respected reports

29 years old silicone laminated PV panels (Japan)

Conclusion

Siloxane gel laminated PV panel annual degradation is -0.15% to -0.22% while EVA laminated PV panel annual degradation is from -0.8% and up to -4.9%

Comparing with EVA laminated panel, Silicon gel laminated panel strongly reduces corrosion of solar cell and interconnect break. The lifetime of silicon gel panel will be 3-4 times longer compared to EVA panel.

The silicon gel panel degradation is about 12-13% over 50 years service time.