

**New PV panel renovation/repair and PV  
panel lamination technologies for  
demanding climate using polysiloxane**

[www.inova-solar.com](http://www.inova-solar.com)

[info@solar-solar.com](mailto:info@solar-solar.com)

# The challenge

- First tier (bankable) PV panel manufacturers declare PV panel lifetime 20-30 years, workmanship warranty 12-15 years.
- Real field lifetime of new PV panels, till critical reduction of PV panels WET Risol (ground impedance), is about 5-7 years 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 100x reduced compared to DRY panels at laboratory tests**

# The reason

Fast reduction of insulation resistance Risol (ground impedance) is observed after 5-7 years in demanding/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 et al.**, 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/Ref.No.	Senegal [5]	Ghana [6]	India [7]	Morocco [8]	India [9]	Thailand [10]
Annual degradation	2.96%	3.19%	2.5%	2.6%	20%	2.7%
Outdoor exposure	4 years	12 years	10 years	3 years	2.5 years	3 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. Alp, [IEEE Access](#) 9(2021). DOI: [10.1109/ACCESS.2021.3096982](https://doi.org/10.1109/ACCESS.2021.3096982)

**Within last 13 years price of PV panels was reduced about 11 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  $R \cdot I^2$

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 off 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 – 5<sup>th</sup> 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 420W panel (size 1x2m). GW



**6<sup>th</sup> 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 420W panel (GW volume)





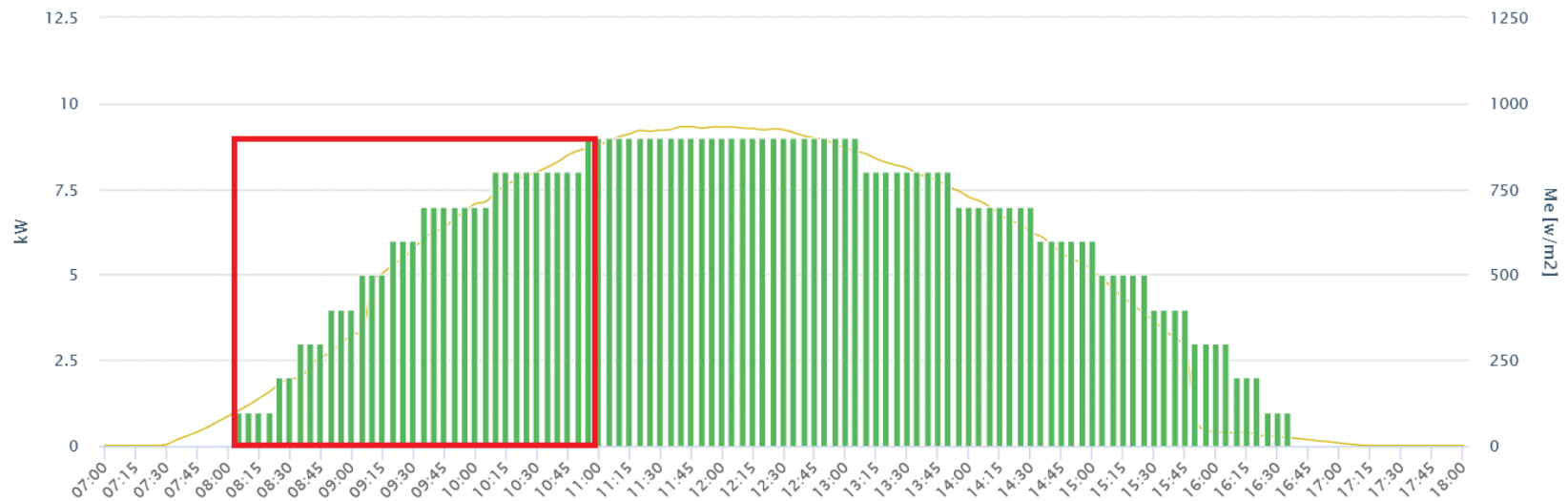
**7<sup>th</sup> year**

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 500 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.

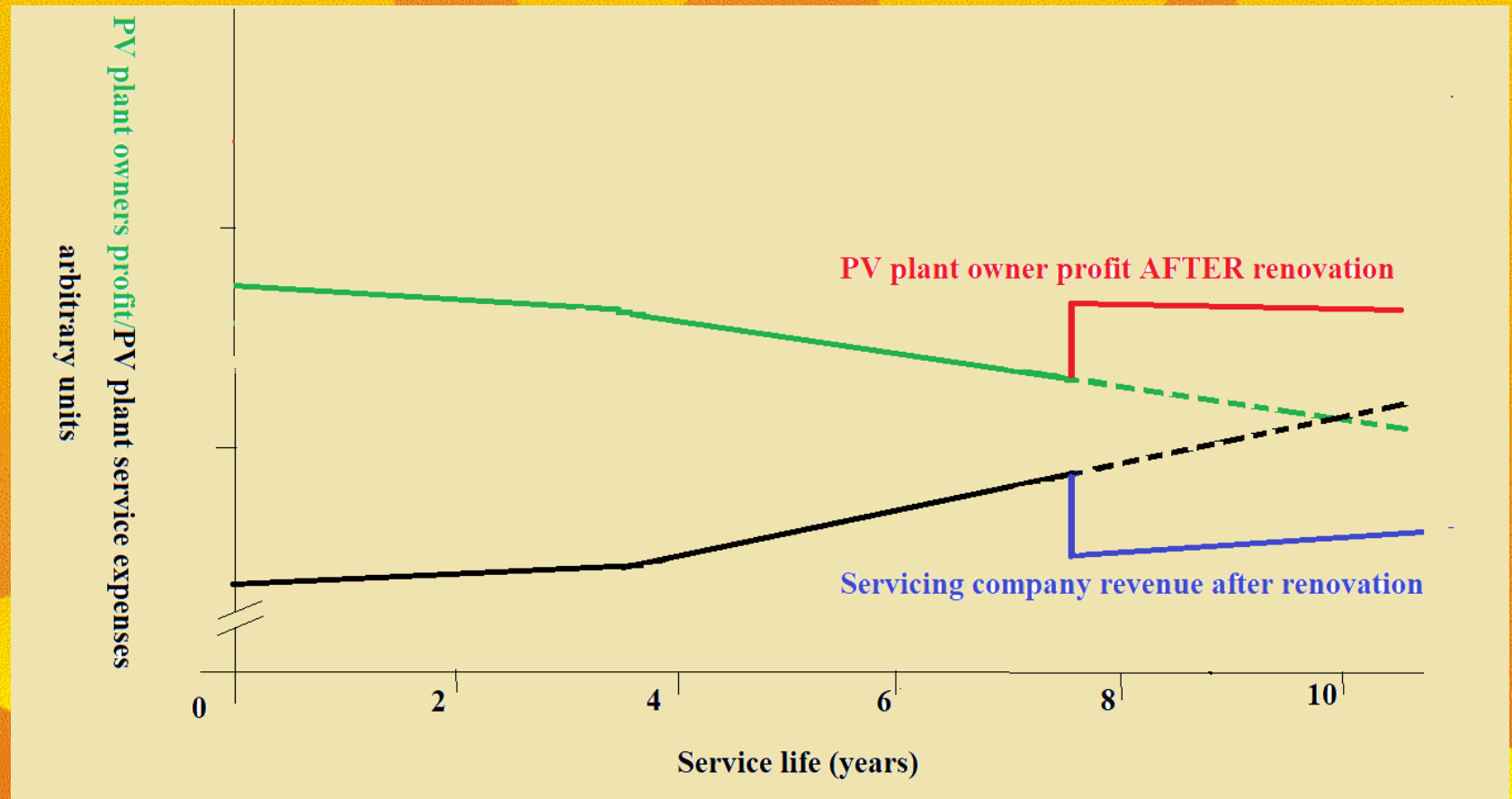
Typically whatever cheap paints were tested but reliability/lifetime was low.

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



# Role of the servicing companies

PV power plant servicing companies usually prefer PV panel replacement to PV panel renovation/repair for simple reason. Their margins on PV panel replacement (120U\$) is bigger compared to PV panel renovation (6 U\$). See picture below. The motivation of PV power plant owners is just opposite.



# The solution

## A) PV panel renovation/repair

Usual replacing of degraded/damaged PV panels by new ones is very expensive method. Additionally 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 20 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....**

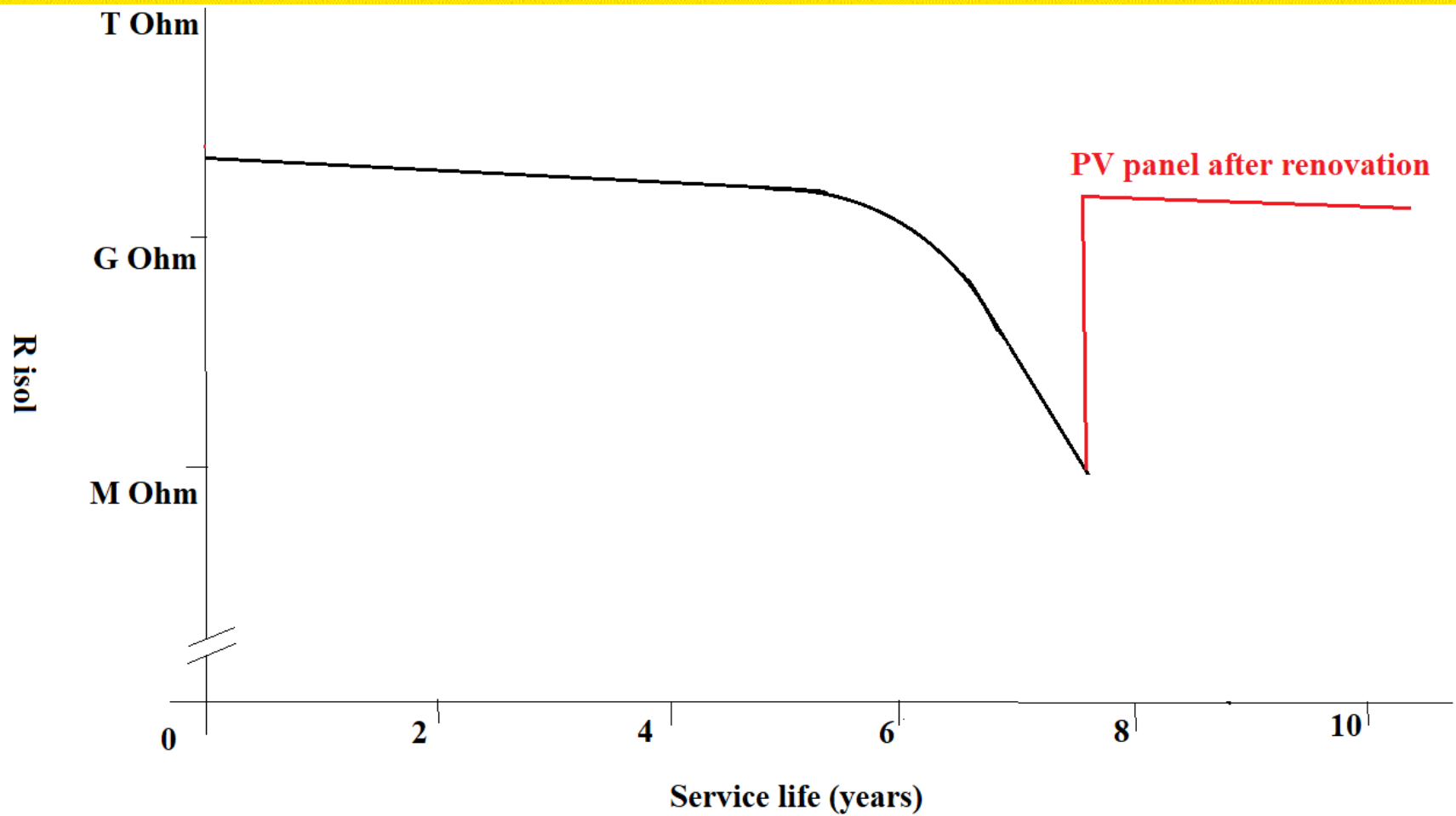
**Renovation film properties (film thickness, uniformity....)**

**Final after renovation check (Risol....)**

**Verification check after 5 years**

# PV panel back side after siloxane film application





Early morning (wet) PV panel insulation resistance before and after renovation by polysiloxane layer





PV panel renovation equipment at 3MW PV power plant

# The carbon footprint

Renovation by siloxane film results in PV panel real life extension by up to +50%, the PV panel carbon footprint increase is about +0,3% only.

Using standard replacement of damaged PV panel by new panel the carbon foot print increase is above +40%

So from the carbon foot print point of view, the siloxane film renovation is more than 100 times more effective compared to PV panel replacement method.

# References

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

# The advantage

**Low cost consumables 6 USD (420W panel 1x2m) GW order**

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

**Pay back time about 5 months**

**Prevents complete damage of inverters (due to multiplication effect)**

**PV panel life extension +30 ~ +50%, carbon footprint +0,3%**

**Fast renovation- 4 minutes per panel**

**PV power plant renovation cost is ~3.5% of total plant cost**

**Improved back sheet abrasion resistance**

The background of the slide is a vibrant yellow with a subtle, fine-grained texture. Overlaid on this background are several large, stylized, flame-like or sunburst-like shapes in a darker, burnt orange or brownish-yellow color. These shapes are arranged in a circular pattern, suggesting a sun or a stylized fire. The overall aesthetic is clean and modern, with a focus on warm, natural colors.

**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%

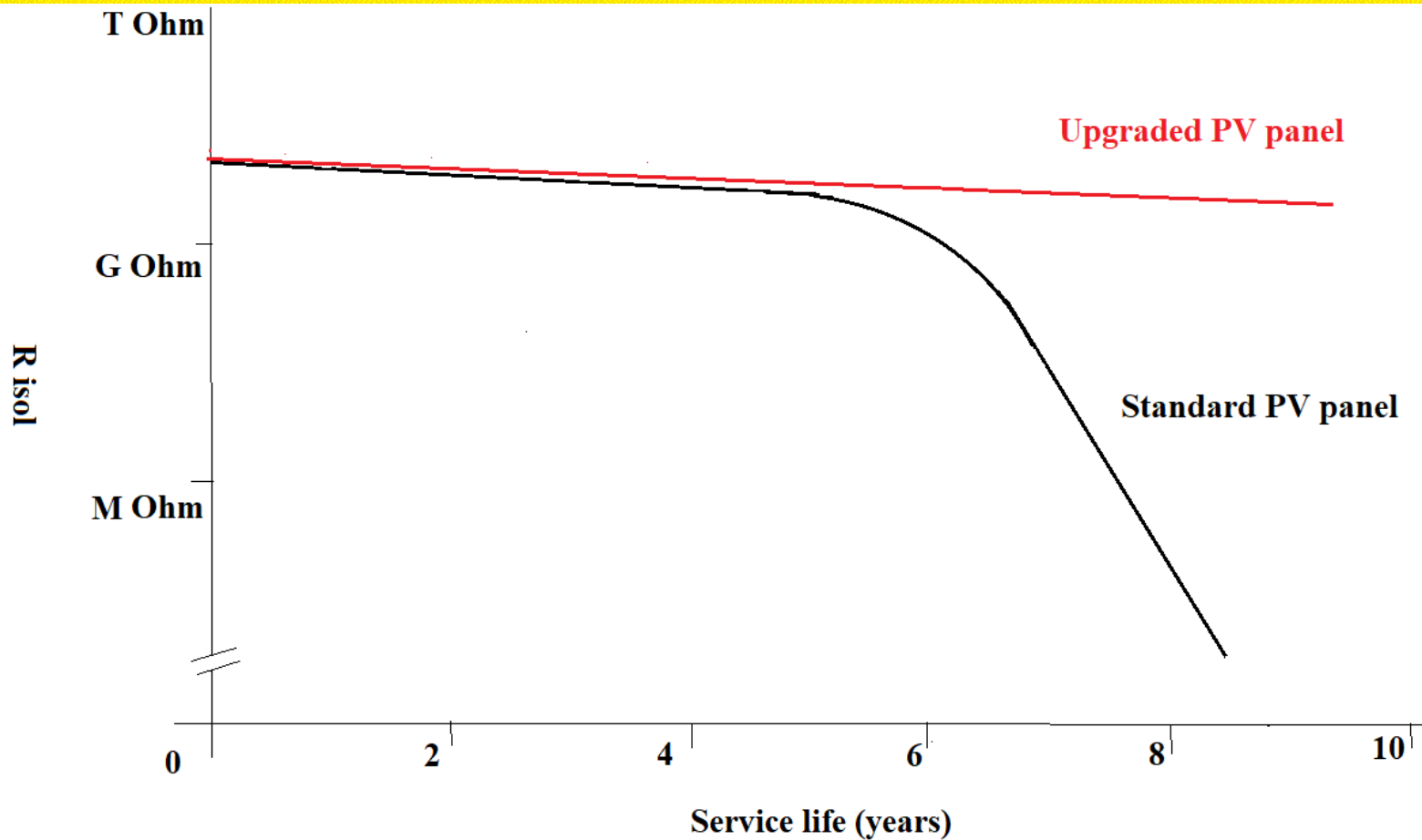
# PV panel back side after siloxane film application



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°C up to +150°C.



PV panel laminated by polysiloxane



# Advantages of silicon gel

- Inert and hydrophobic material
- Temperature resistant material  $-55^{\circ}\text{C} \sim +250^{\circ}\text{C}$
- Highly transparent material
- Low production energy consumption
- Environmental safety

## Tab.2 comparison of EVA and siloxane gel properties

	<b>EVA</b>	<b>Siloxane gel</b>
long term operational temperature	<b>-40°C, +80°C</b>	<b>-55°C, +150°C</b>
UV radiation resistance	low	high
operationnal life time	20-30 years (5-9 years real)	50 years real
long term annual degradation	<b>0.8%-4.9%</b>	<b>0.15%-0.22%</b>
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-ageing	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 Encapsulated Solar Panel



- Operating temperature  $-55^{\circ}\text{C}$  to  $115^{\circ}\text{C}$
- Glass-Glass solution for bifacial technology
- lifetime up to 50 years
- Eliminates over 80% of standard panel failures.
- Panels are fireproof

PV panel load test at  $-55^{\circ}\text{C}$

## Tab.3 Specification of Silicon gel encapsulated Solar Panel

Maximum Power at STC (Pmax)	540W
Maximum Power Voltage (Vmp)	49,12V
Maximum Power Current (Imp)	11,06
Open Circuit Voltage(Voc)	58,95V
Short Circuit Current (Isc)	11,28A
Module Efficiency	18.3%
Operating Module Temperature	-55°C to +115°C
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	37.5kg (glass/glass)

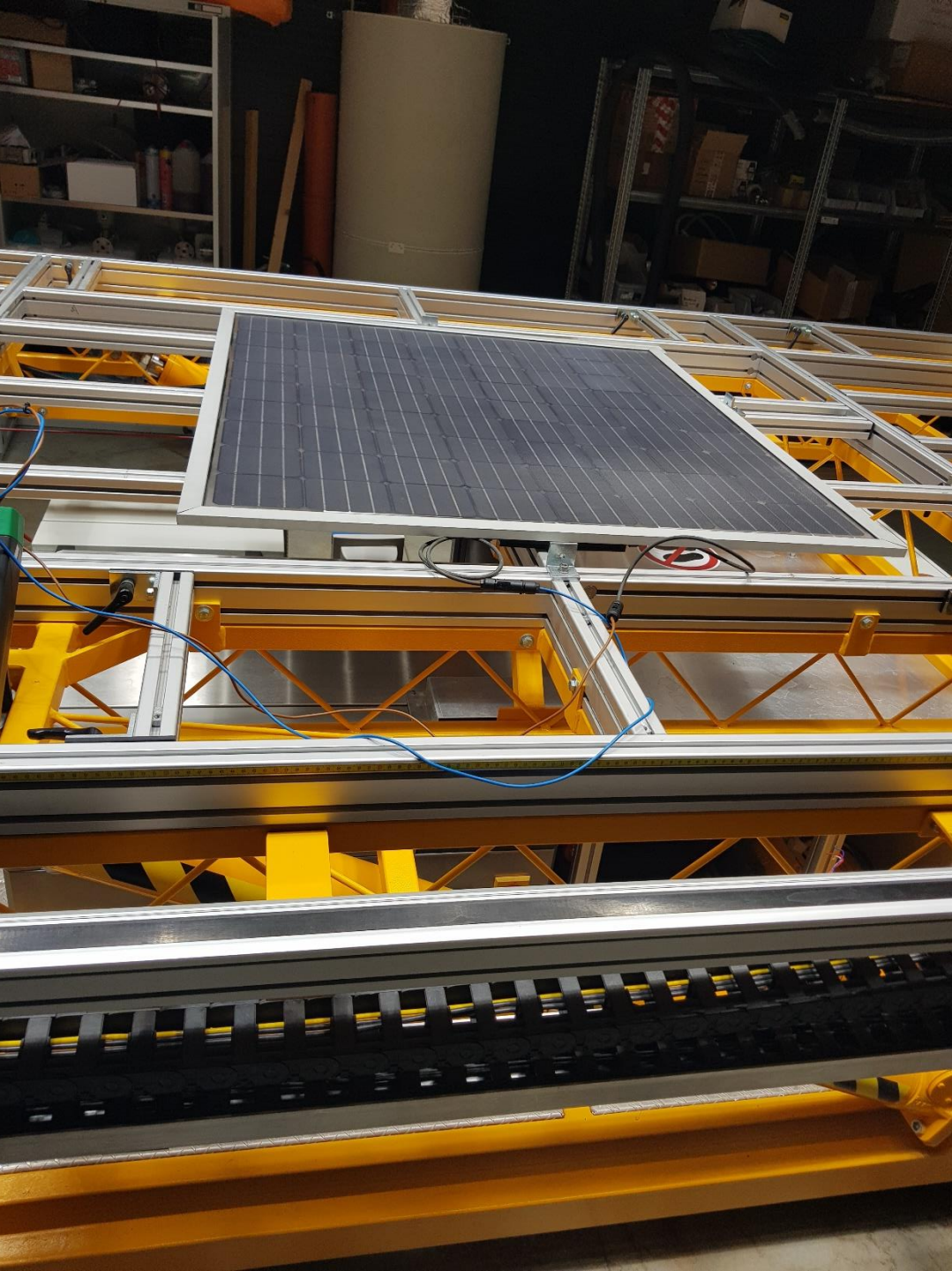
Evaluation of panels laminated by silicone gel

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)	0.22%
Czech, Prague	Traxle	Russia	Glass/glass	mono	2010-2022 (12 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.