ESTI
European Solar Test Installation

Long-term performance of photovoltaic modules

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- The European Solar Test Installation (ESTI) has the primary objective of providing the scientific and technological basis for a sound and credible assessment of all aspects of photovoltaic energy

- It assists both policy makers and industry, and provides scientific input to standards organisations and national agencies

- Over the past 25 years, ESTI has developed into one of the worlds leading laboratories for photovoltaic reference measurements

- Main activities (Testing and Calibration Services):

  - Accelerated stress tests based on the IEC 61215 and IEC 61646 standards

  - Module and photovoltaic cell calibration

3 case studies of long-term weathered PV modules

Performance of long-term weathered silicon wafer based modules at the JRC test site

Performance of 10 kWp PV plant based on a single type of crystalline silicon wafer based module at the LEEE-TISO

Performance of the large 21 kWp thin film (a-Si) facade at the JRC site

Case 1: Outdoor exposure test site in Ispra

The original idea of the experiment in the 1980's was to test small PV battery charger connected systems (charger with MPPT capabilities)

The climatic conditions:

Ispra ESTI test site – Northern Italy, Altitude 220 m above sea level

Moderate subtropical climate (–10 °C to +35 °C with less than 90% rh)

Characteristics of the tested PV modules

- 204 crystalline silicon-wafer based photovoltaic modules (53 module types originating from 20 different producers)

- Modules are rated from about 8 Wp up to 117 Wp, (average of 40 Wp)

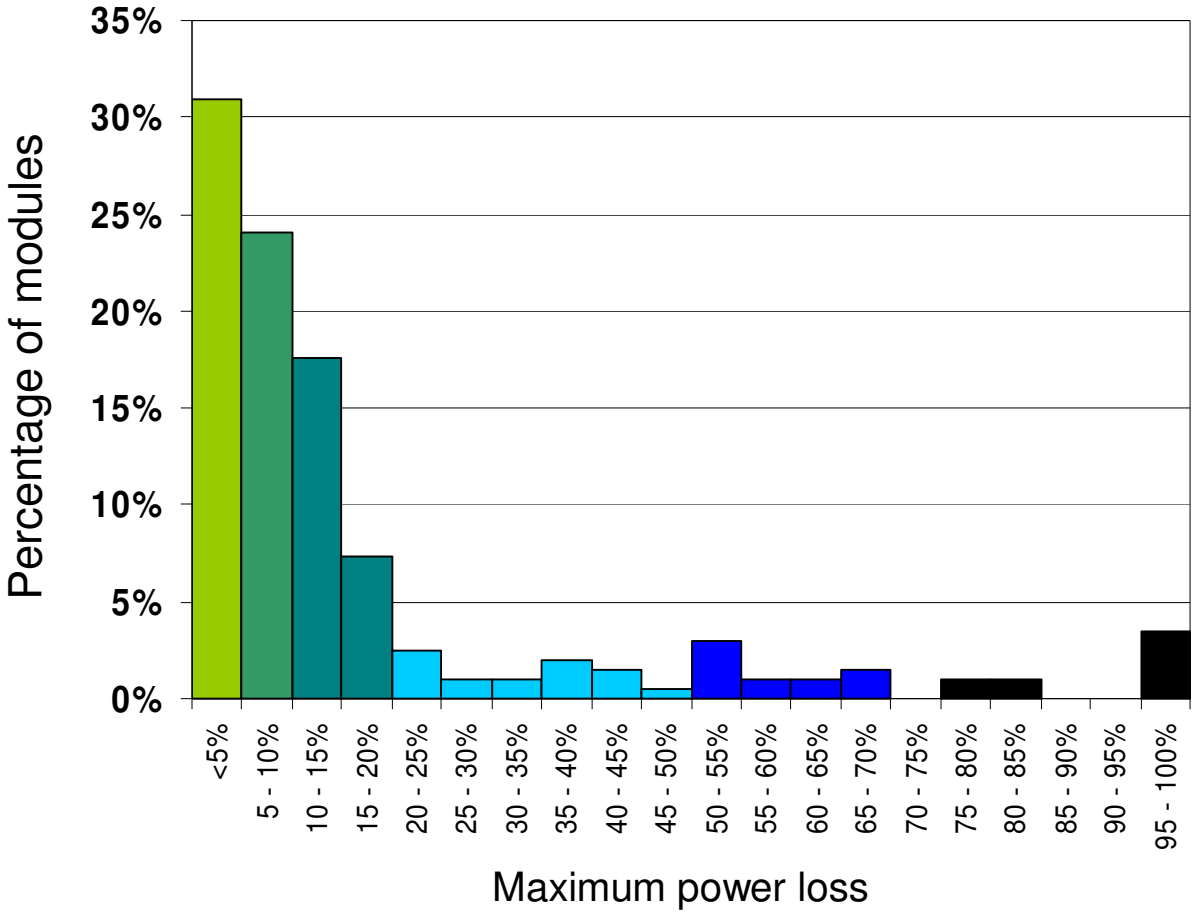
- Encapsulants used: Ethylene-Vinyl Acetate (EVA) – 29 types
  Polyvinyl butyral (PVB) – 14 types
  Polysiloxanes (Silicone) –8 types

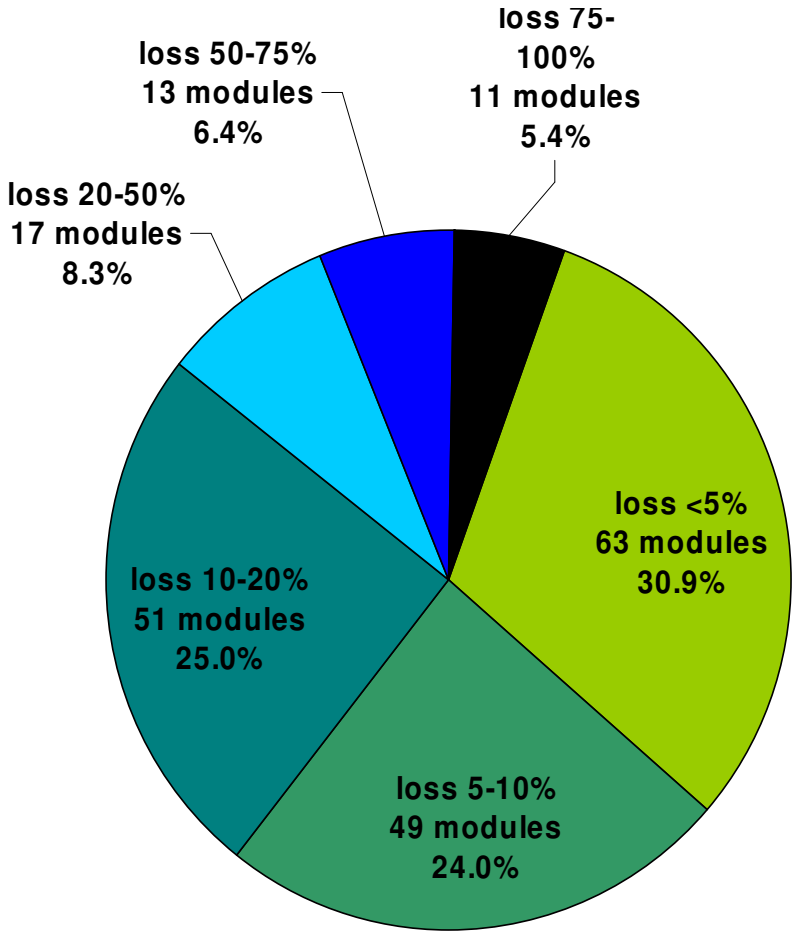
- Back substrate used: Polyvinyl fluoride (Tedlar) – 21 cases
  Glass – 17 types
  Silicone – 5 types
  Polyester / aluminum – 4 types
  Polyethylene – 1 type

- 31 mono and 22 polycrystalline based module types

Overal results from electrical perfomance measurements

Histogram of P_{max} losses of all 204 weathered modules





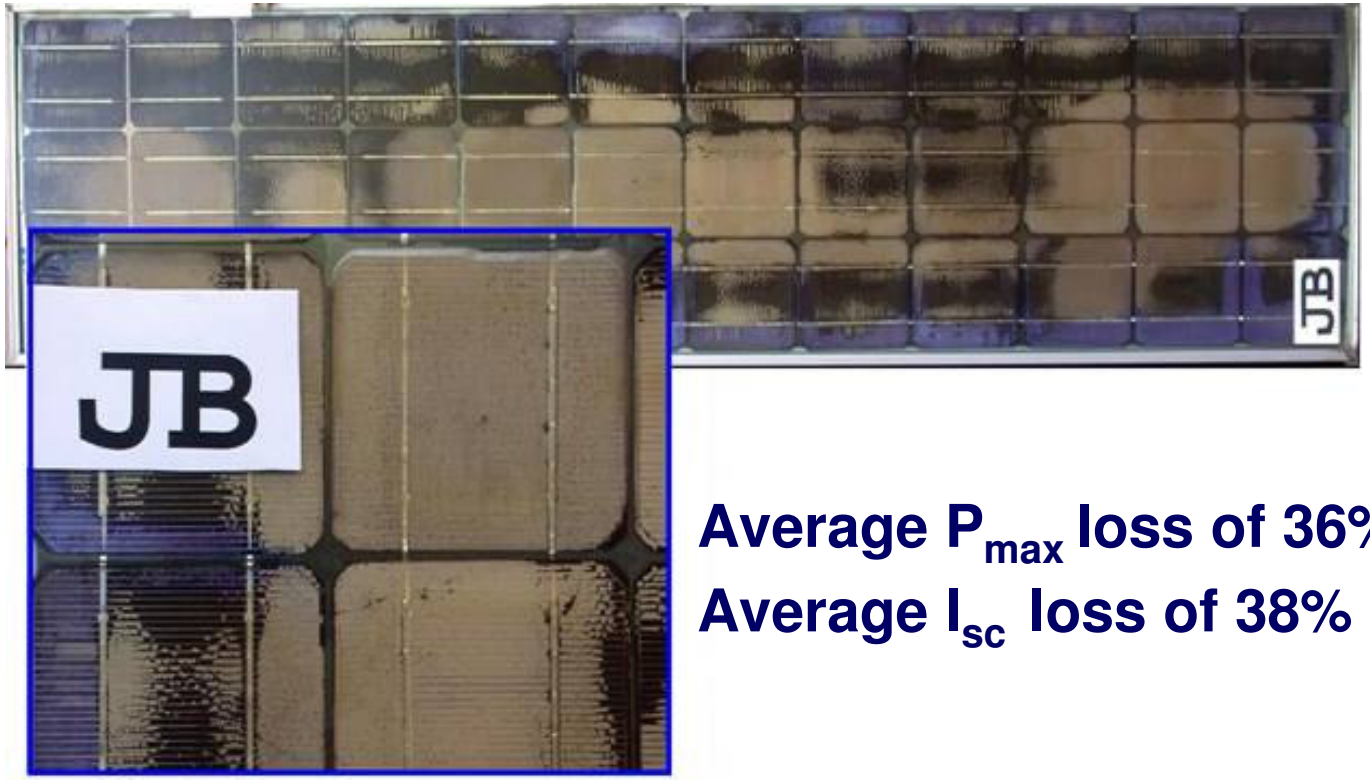
Visual inspection results

The main type of visual defects observed on weathered modules

- encapsulant browning (cell area and/or the whole module front surface)
- delamination and bubble formation in the encapsulant
- back sheet polymer cracks
- front surface soiling/frosting
- blackening at the bottom edge of the module
  (ingrained dirt not possible to remove)
- junction box connections corrosion
- busbar oxidation and discoloration
- junction cables insulation degradation (modules without junction boxes)
- glass breakage (1 case of back sheet and 1 of the front surface)

Visual inspection results

Encapsulant browning,
bubble formation in the encapsulant

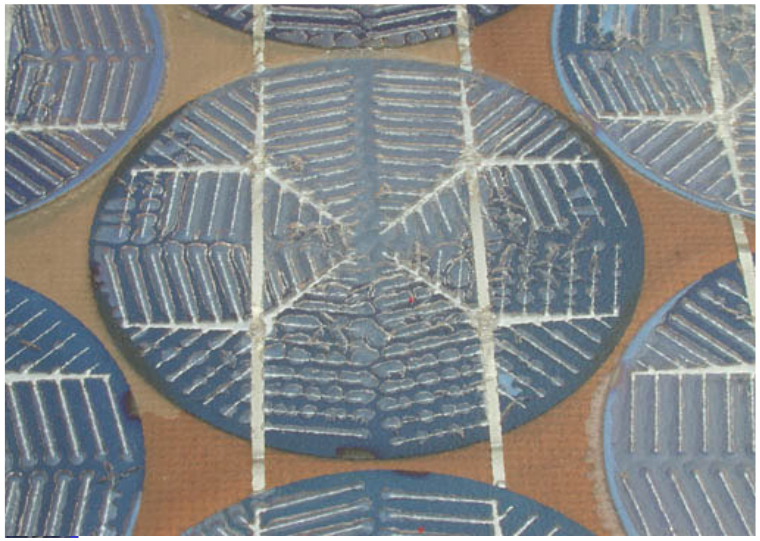


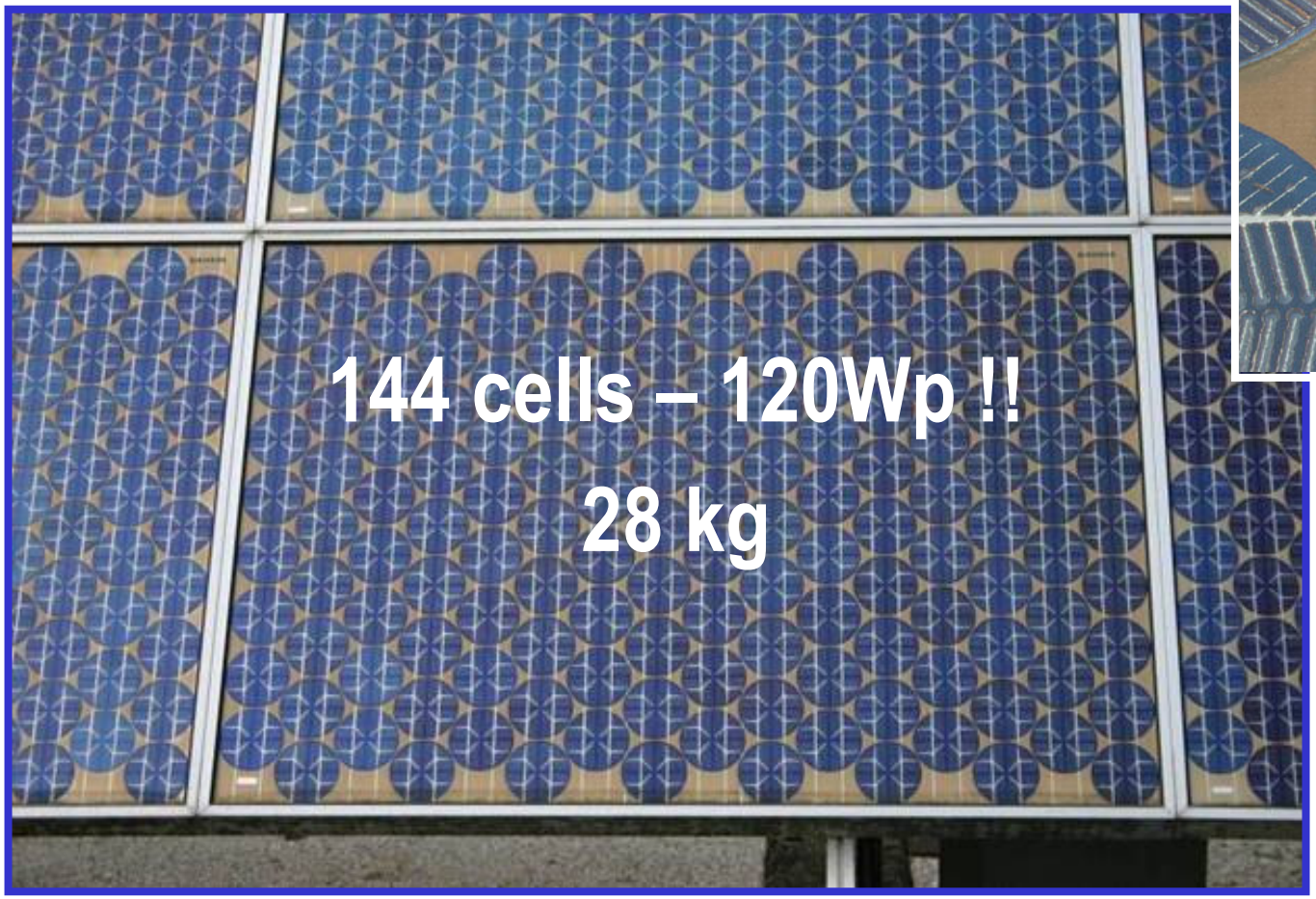
Average P_{max} loss of 36%
Average I_{sc} loss of 38%

Side by side with the AC series (13% average P_{max} loss)

Visual inspection results

Example of Severe Discoloration and Delamination



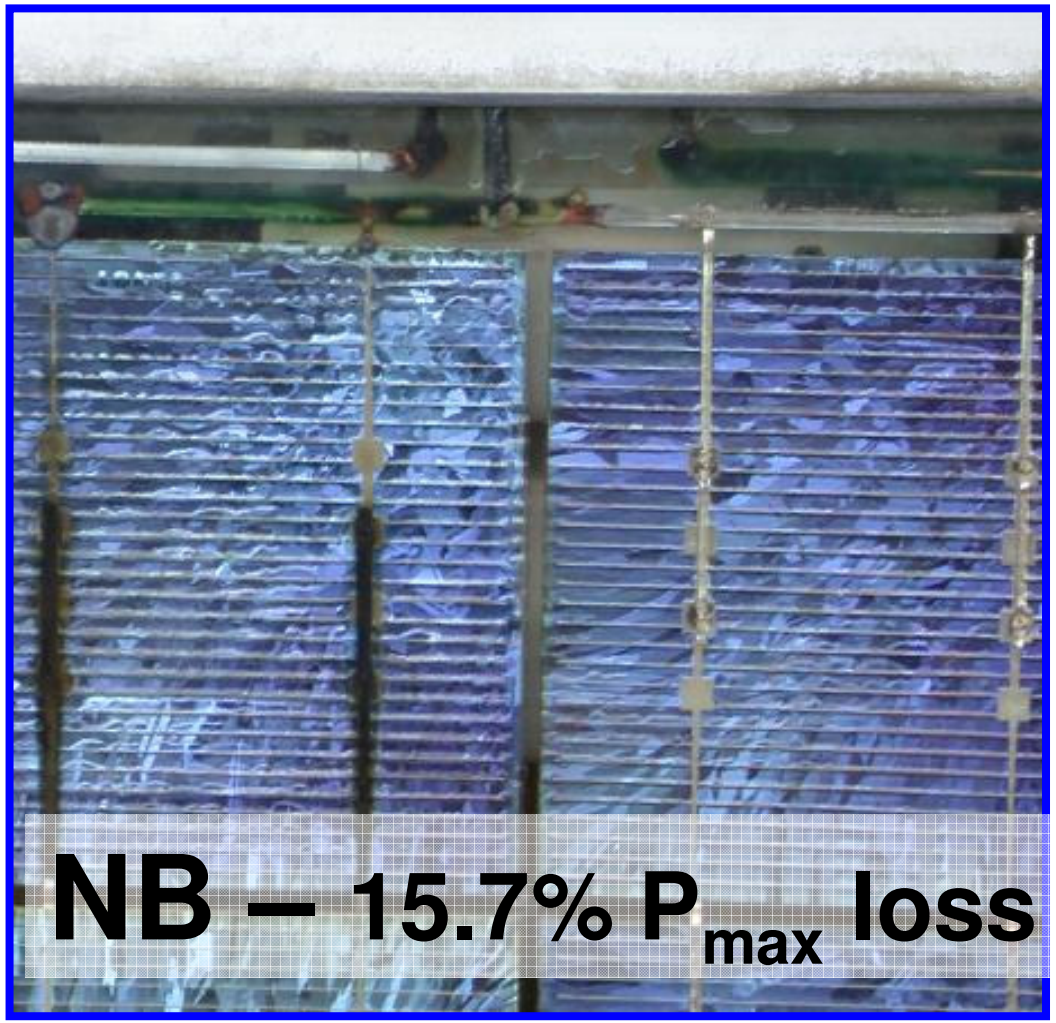


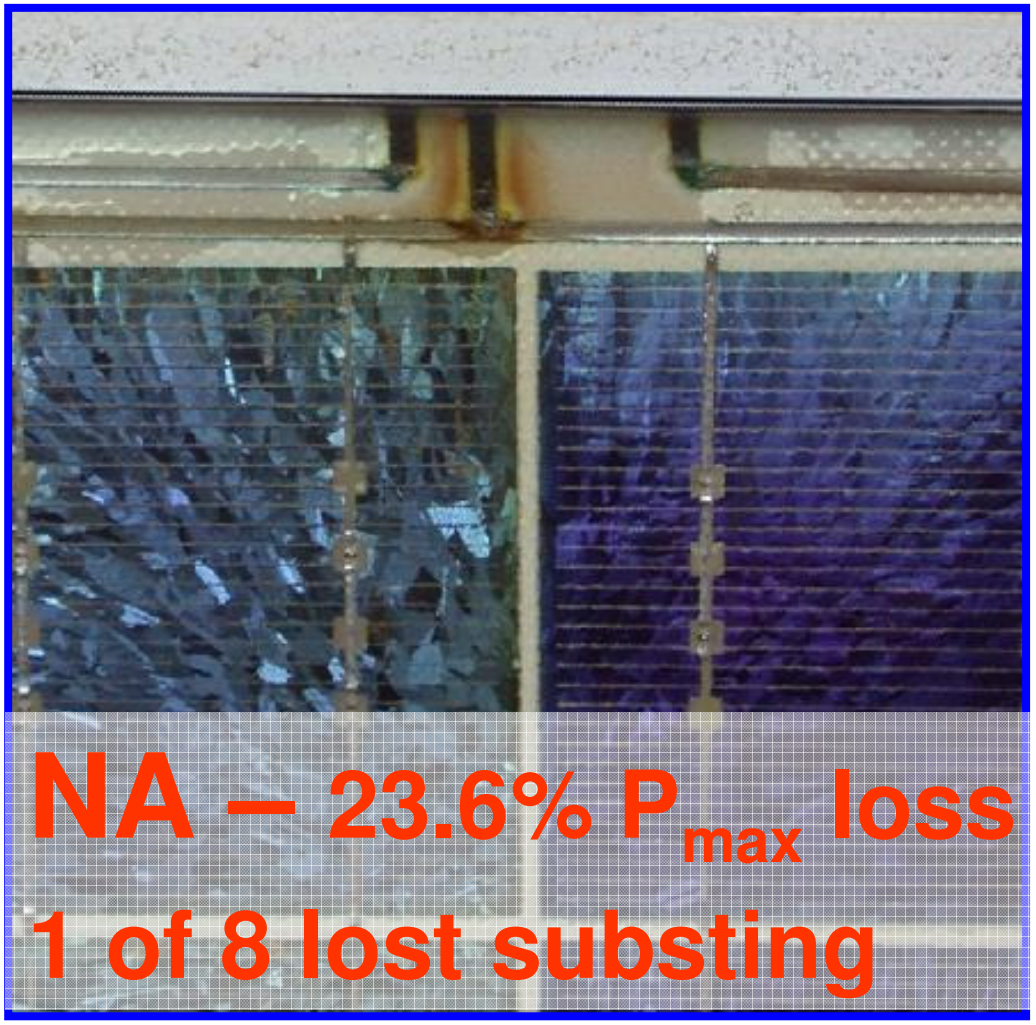
Average P_{max} loss of L0, LA, LB series 14.8%

2 modules exibit P_{max} loss of ~1%

Visual inspection results

Busbar oxidation and discoloration





Visual inspection results

A set of 20 year old PV modules exposed at the JRC test site which show no visible signs of degradation but exhibit a high maximum power loss

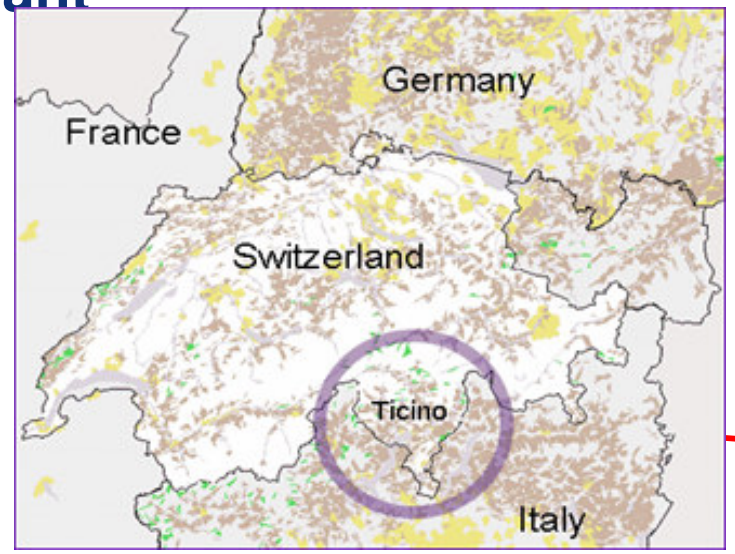
Average P_{max} loss: 52%

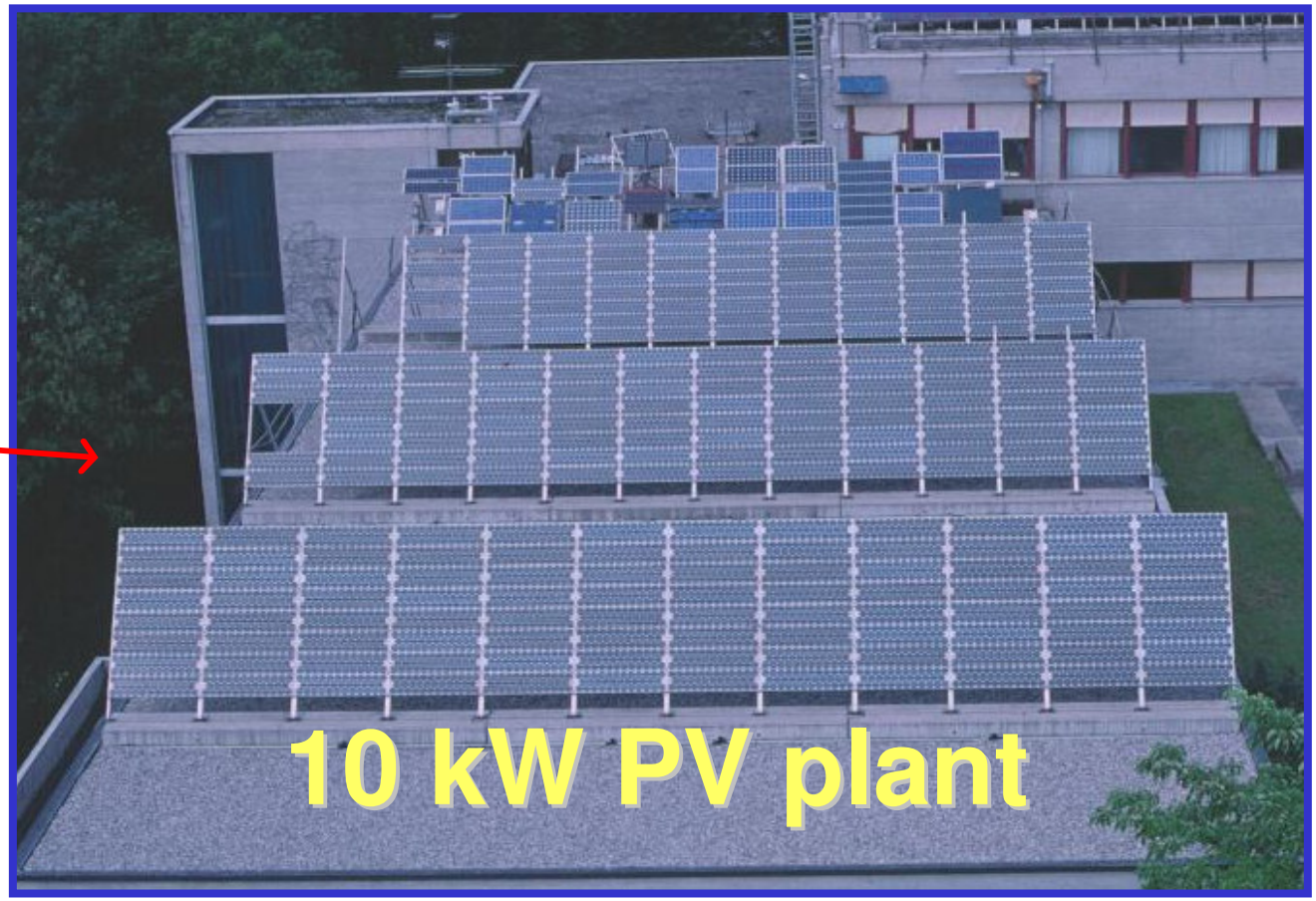
Conclusions

- There is no statistically significant difference in the performance of the modules with monocrystalline and polycrystalline cells (average degradation rate 0.7% per year)
- The visual appearance of field–aged modules is often not correlated with their electrical performance and state of electrical insulation
- Of the 204 modules studied in this work 82.4% have been verified to have the final maximum power greater than 80% of the initial power i.e. meeting the manufacturers warranty criteria
- Furthermore two thirds of modules have the final maximum power verified to be more than 90% of the initial power value after >20 years of outdoor exposure.

Case 2: 10 kW PV plant at the LEEE-TISO Lugano

Collaboration between TISO and ESTI to look at the aging of the PV power plant





252 Arco Solar

ASI 16-2300 modules

35 m-Si cells, PVB encapsulant, Tedlar/Al/Tedlar backsheet

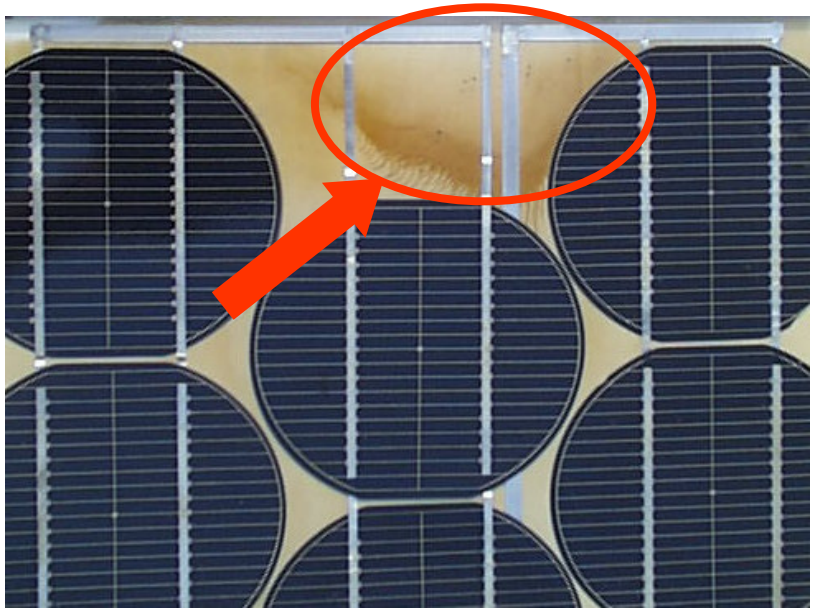
1982: Initial aim - To study technical and safety problems of a PV plant connected to the grid

2000-2003 - Plant MTBF (mean time before failure) determination

- **Investigation of physical degradation mechanisms**
- **Field reliability/accelerated lifetime tests (CEI/IEC 61215) correlation**

Visual inspection results

Browning



- 98% of modules (2003)
  (~50% in 1985)
- 78% exhibiting complete coverage of tedlar
  (63% dark yellowing)
- Darker spots
- No influence on encapsulant transparency
  (same spectral response for white and yellow modules)

Visual inspection results

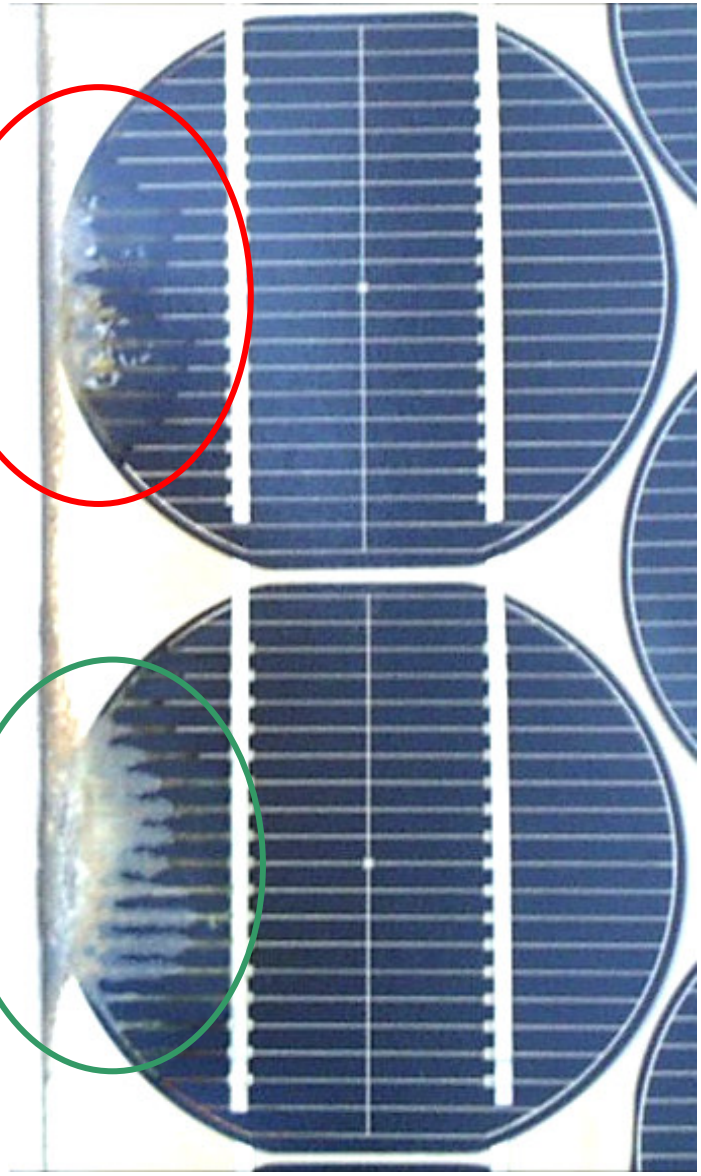
Delamination

- 92% of modules (74% in 1996)
- No effects on modules insulation (dry & wet insulation tests)

Effects on modules performance

Delaminated area: 3.0%
ΔP_{max}: -6.5%, ΔI_{sc}: -3.4%

Delaminated area: 8.3%
ΔP_{max}: -18.3%, ΔI_{sc}: -11.7%

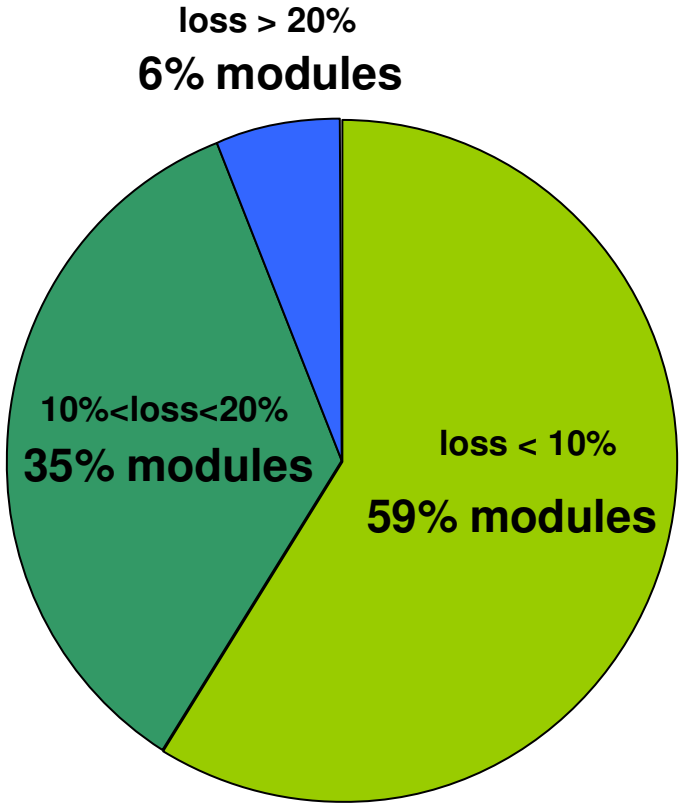


Indoor IV Measurements of 18 reference modules

- 13 stable modules power loss: -1.7% vs 1982
- 5 degraded modules power loss: -9.1% vs 1982

(2 hot-spot, 1 damaged cell)

Overal performance of
20 years old modules



Conclusions for the 10kW TISO Plant

Good 20-year old technology

- Not good looking, but perfectly functioning plant
- Hot-spots
- Delamination
- Remarkable modules resistance of old modules to repeated indoor Damp Heat and Thermal Cycling
- Good expectation for at least 30 year lifetime?

Degradation rate of silicon-wafer PV modules

Detailed analytical data of the progressive degradation of PV modules is not readily available
Two noticeable exceptions are:

- **Realini et. al. For a crystalline silicon array, with Arco Solar ASI 16-2300 modules. Average weighted degradation of 5.2%, over the 19 years of operation (0.4% per annum including initial degradation)**

- **Reis et. Al. For a crystalline array, with Arco Solar M-75 modules. Average degradation of 4.39% in 11 years (0.4% per annum including initial degradation)**

Degradation rate of silicon-wafer PV modules

- The remarkable agreement between these two publications would indicate that in fact it is a consistent and reliable estimate of the continuous degradation effects

- However this is less than reported for other sources Quintana et. al. (0.7% or higher) but may be attributed to the high level of maintenance and replacement of components as indicated in the previous examples

Summary:

- Short Term Losses: have been shown to be in the order of 2.4% ± 1.7%.

- Long Term Losses: have been shown to in the order of 0.2% per annum

up to 0.7% per annum (exluding modules with total circuit faliure)

Case 3: The large thin-film a-Si Facade at the JRC Ispra

The system is mounted on a vertical south-facing wall of a building housing

a large research facility

First connected to the grid

in August 1994

The dimensions: 61 m x 12.6 m

total area: 770 m^2 (active 505 m^2)

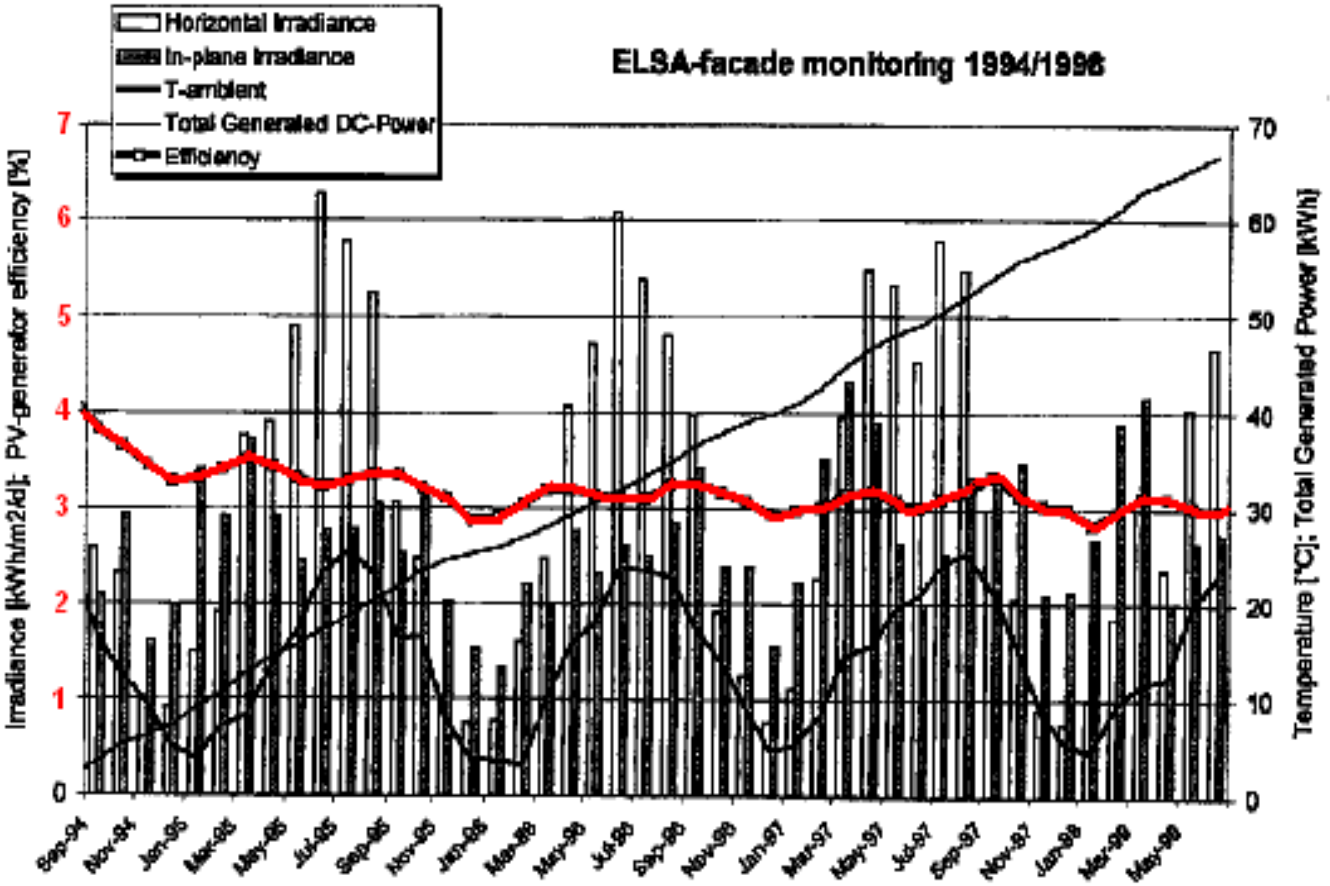
420 thin-film a-Si modules by

Advanced Photovoltaic Systems

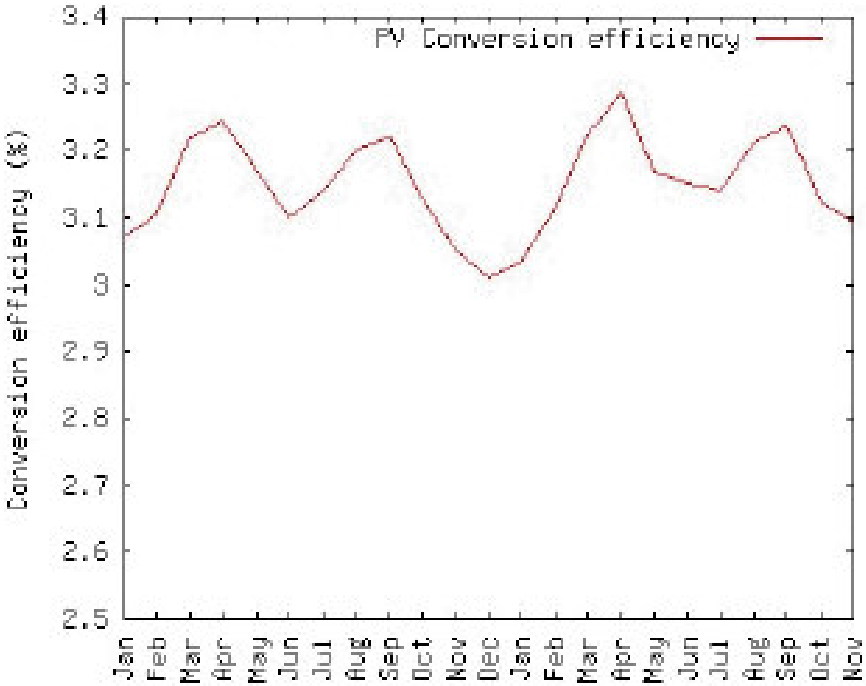
The design peak power after

the initial degradation: 21kW

Evolution of the system performance during the period of operation



September 1994 to July 1998



January 2004 to November 2005

Presented at:
2nd World Conference on Photovoltaic Solar Energy Conversion, Vienna, Austria, July 1998, C.Helmke, et. al.
Four years of Operation of the Largest Amorphous Silicon Photovoltaic Facade

Presented at:
IEEE 4th World Conference on Photovoltaic Energy Conversion, May 200
Huld, T.; et.al. Analysis of the performance of the Large Amorphous Silicon PV Facade in Ispra after 11 years of operation

Conclusions from the operation of a-Si thin film facade

- The results from performance analysis show that all 420 modules in the system are still operating
- Detailed measurements of part of the system indicate that the nominal peak power remains at the design value of 21kW
- The conversion efficiency of the a-Si modules have now stabilized at a value of around 3.2% with some seasonal variation
- Altogether the system has had an uptime > 99% The total amount of energy produced during 11 years of operation is around 153 MWh

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Thank You for your attention

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