Silicon Heterojunction Solar Technology at the Gate of the Giga-Watt-Age: Reliability and Long-term Performance

Olatz Arriaga Arruti[1]
Alessandro Virtuani[2]
Christophe Ballif[1,2]
olatz.arriagaarruti@epfl.ch

[1]École Polytechnique Fédérale de Lausanne (EPFL), Institute of Electrical and Microengineering (IEM), PV-Lab, Neuchâtel, Switzerland
[2]CSEM, SE-center, 2000 Neuchâtel, Switzerland

29.09.2022

Olatz Arriaga Arruti

EPFL

PV-lab IEM NEUCHATEL

Outline

1. Introduction

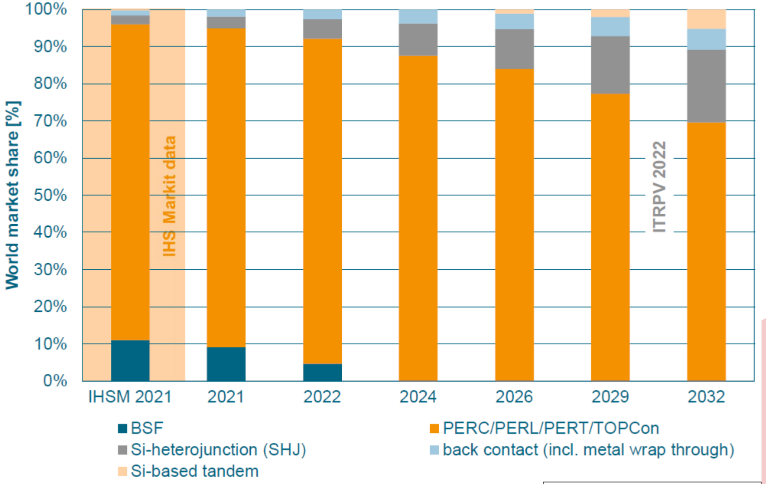
2. Field Performance of Si Heterojunction Modules
3. Indoor Accelerated Stress Testing on Si Heterojunction Technology
4. Conclusions

EPFL

Evolution on solar cell technology

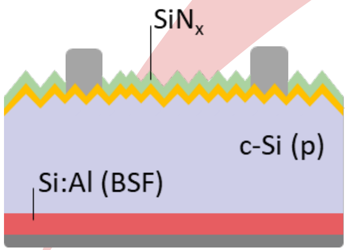
PV-lab
IEM NEUCHATEL

Olatz Arriaga Arruti



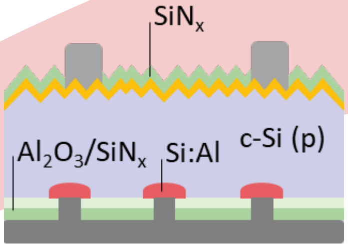
ITRPV (2022)

Al-BSF



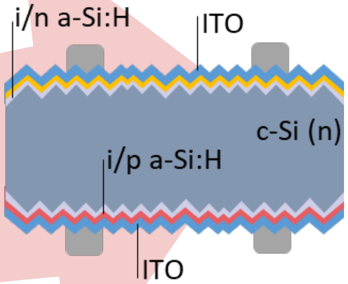
Mainstream c-Si technology until 2014…

PERC



Today's mainstream c-Si technology (**≈80% market share**)

SHJ



Easy to process **bifacial devices** with few process steps (**low cost** with **high efficiency**)

Key technology to restart the PV production in EU

01 April 2022

3 GW/year

Enel Green Power signs grant agreement with the EU for solar panel Gigafactory in Italy

NEWS

Meyer Burger optimising production expansion to 1.4GW in Germany to cater for European demand

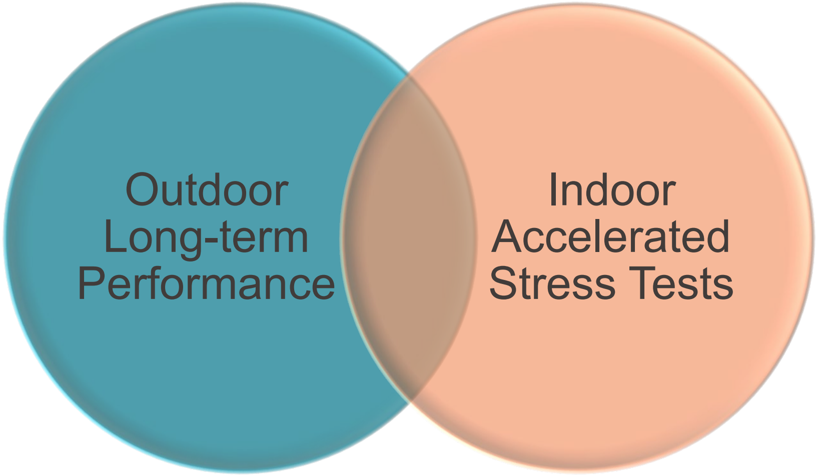
By Jonathan Tourino Jacobo

April 29, 2022

Outdoor Performance vs Indoor Tests

Outdoor Long-Term Performance

- **Commercial technologies** installed in the field.
- Long time-series (ideally over 10-15 years).
- Variety of climatic and operating conditions.



Indoor Accelerated Stress Tests

- Technologies in **development**.
- **No direct correlation** to potential duration in the field.
- Detection of **weak points** ⟶ reliable modules at the manufacturing process.
- No consideration of particular climate or operating conditions.

Novel high efficiency technologies can be more sensitive to degradation

Meta-analysis on outdoor performance and main failure modes of SHJ technology

Outline

1. Introduction

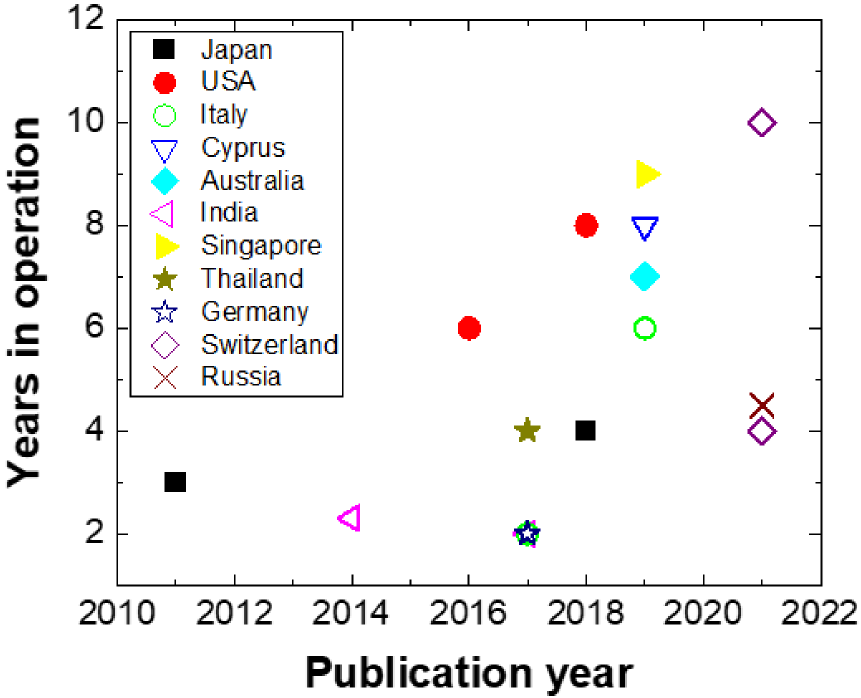
2. Field Performance on Si Heterojunction Modules

3. Indoor Accelerated Stress Testing on Si Heterojunction Technology

4. Conclusions

Literature Review: Methodology

- **54 data-sets from 14 publications**
- Variety of climates (temperate, tropics, arid…).
- **Performance Loss Rates** (PLR) [%/year] considering a **linear degradation**.
- Filtering of high-accuracy data-sets.
- Study of **main failure modes**.
  - From the survey.
  - From indoor accelerated ageing tests.



Arriaga Arruti et al. "*Long-term performance and reliability of silicon heterojunction solar cells/modules*", submitted for publication

Caveats of this meta-analysis

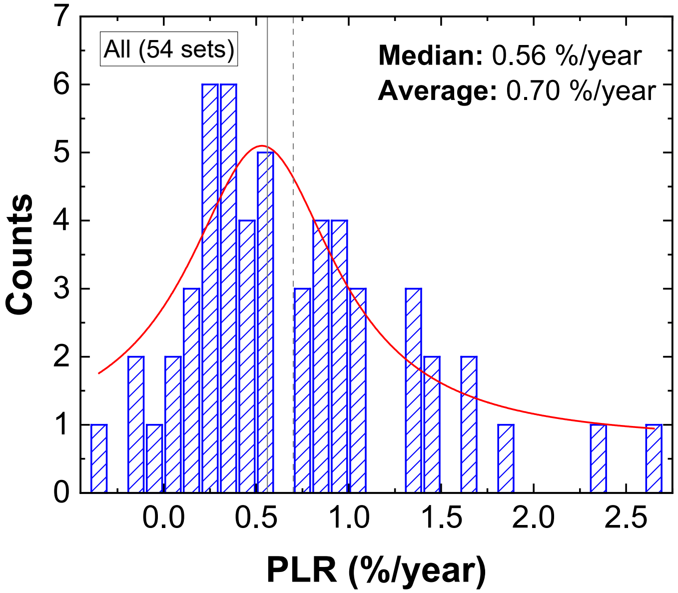
Olatz Arriaga Arruti

- **Sanyo/Panasonic** technology ⟶ changed over the years.
  - **G/BS** module configuration ⟶ G/Al-BS at some point.
    - Currently ⟶ **POE/EVA encapsulation scheme**.
  - Front-emitter technology ⟶ **changed to rear-emitter in 2009**.
- **Limited statistics** and **temporal horizon** (max. 10-15 years).

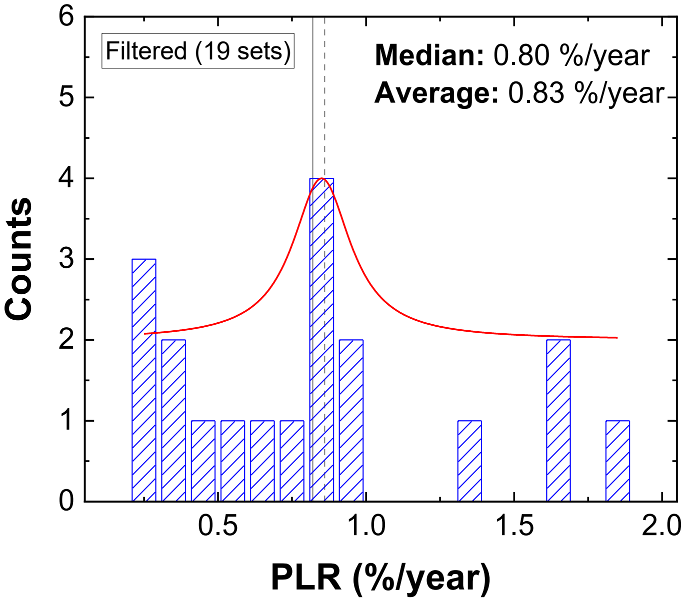
Long-term Performance & Reliability of SHJ Modules

- 54 data-sets from 14 publications

All data-sets

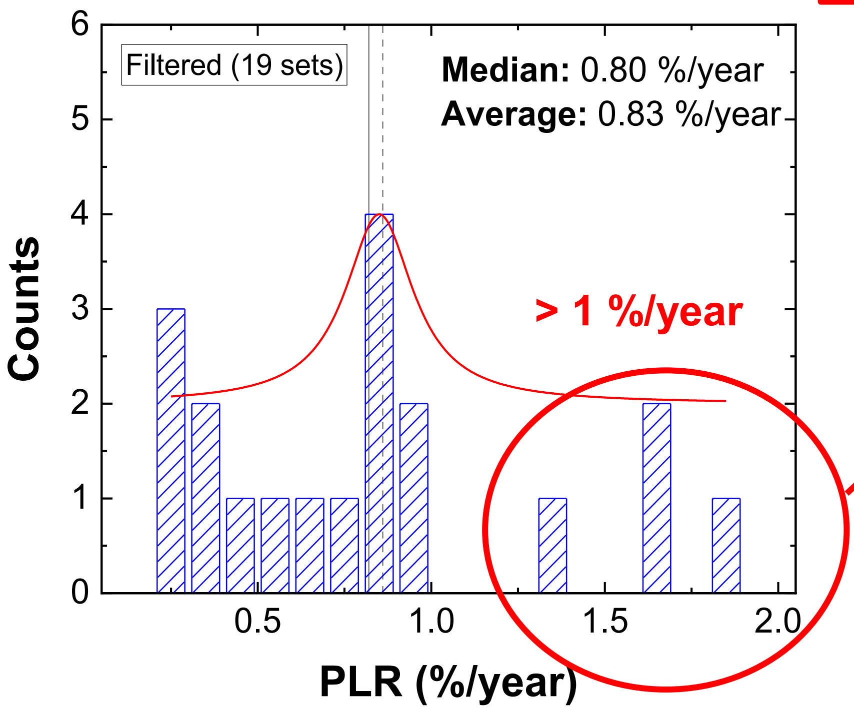


High-accuracy data-sets



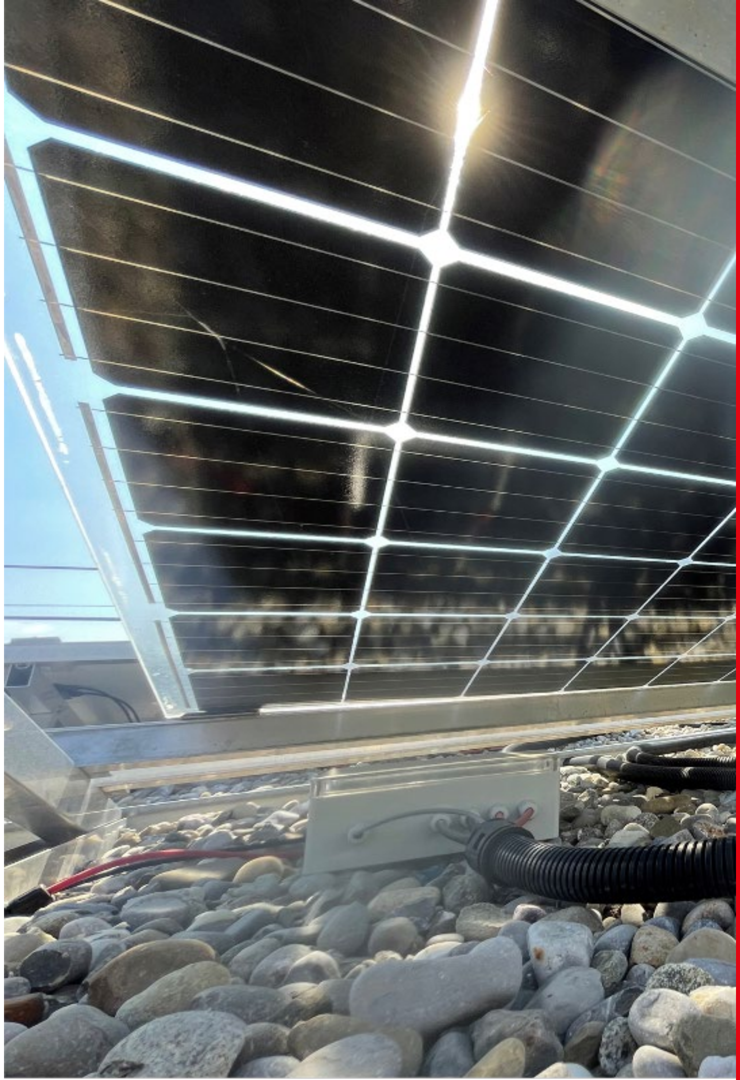
High-accuracy data-sets – Failure modes

Not a clear climate dependence trend



Main failure modes

- Often not studied.
- Loss in V_{OC} (several climates).
- **Encapsulant browning** ⟶ not particular to the SHJ technology.

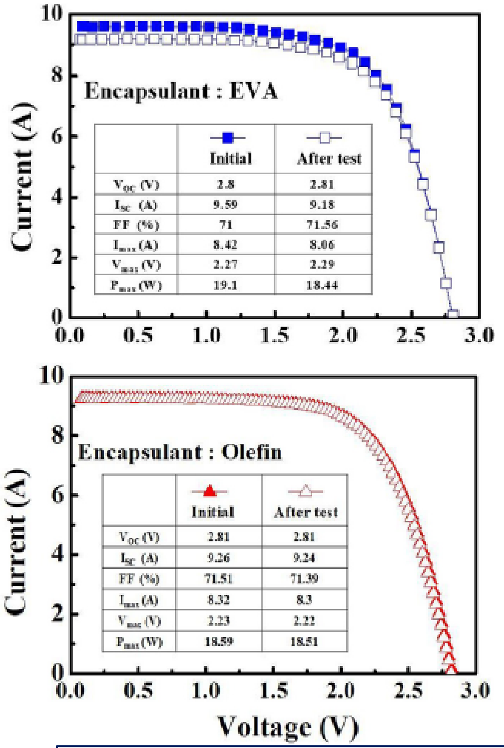


Outline

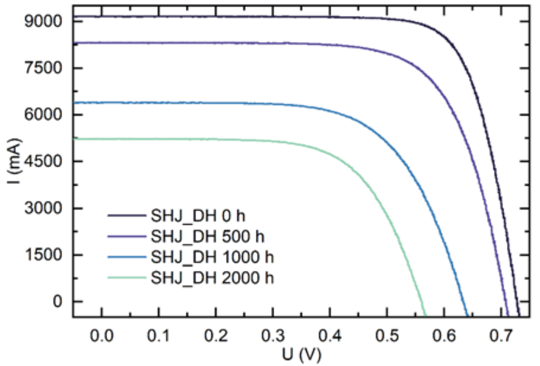
1. Introduction
2. Field Performance of Si Heterojunction Modules
3. **Indoor Accelerated Stress Testing on Si Heterojunction Technology**
4. Conclusions

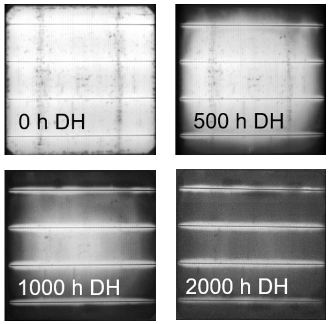
Water/Moisture ingress

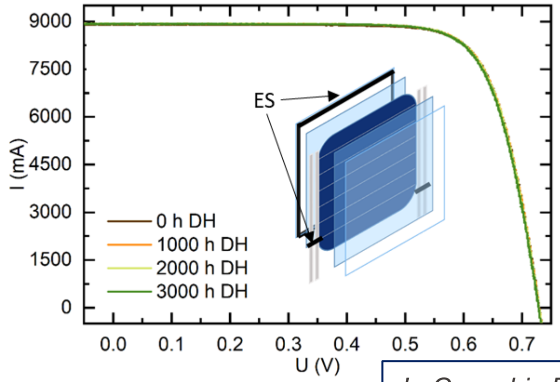
- Highly sensitive to moisture ingress.
- Mechanism is not always the same.



Park et al., *Microelectron. Eng.* (2019)



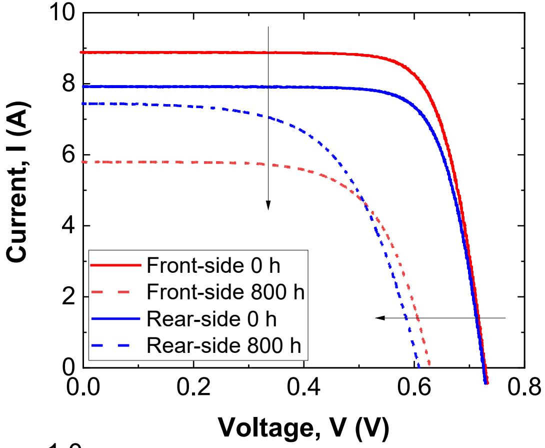


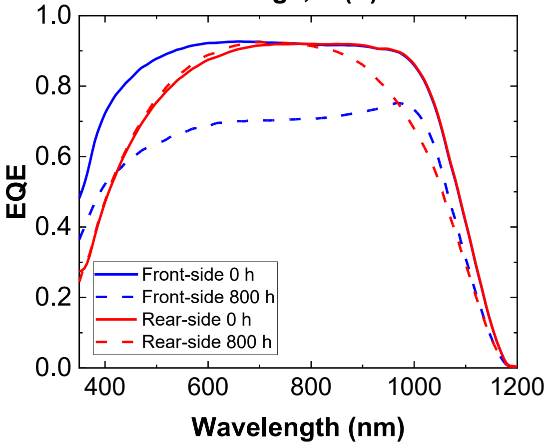


L. Gnocchi., *PhD Thesis, EPFL.* (2022)

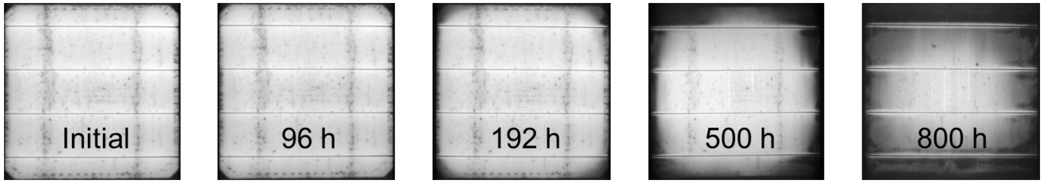
Potential-Induced Degradation (PID)

G/G (EVA)

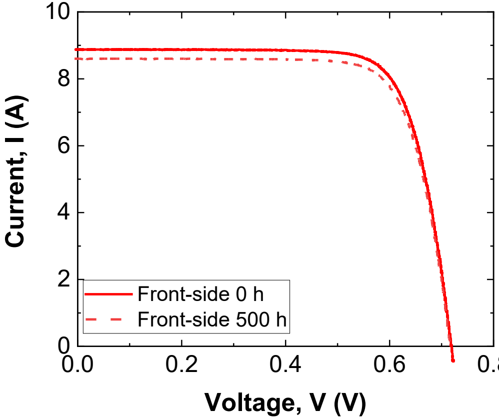




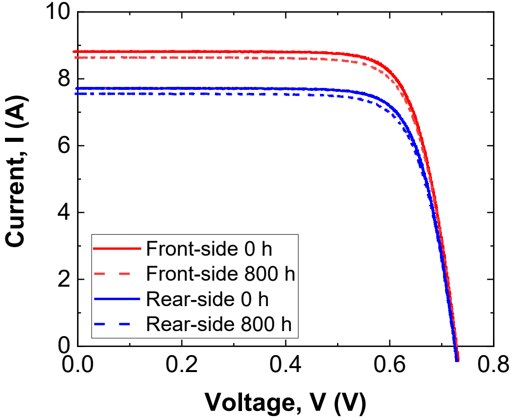
Electroluminescence



G/G (POE)

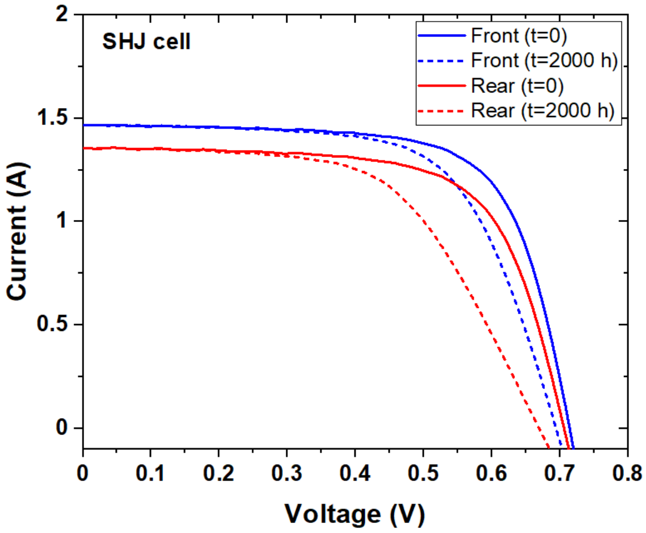


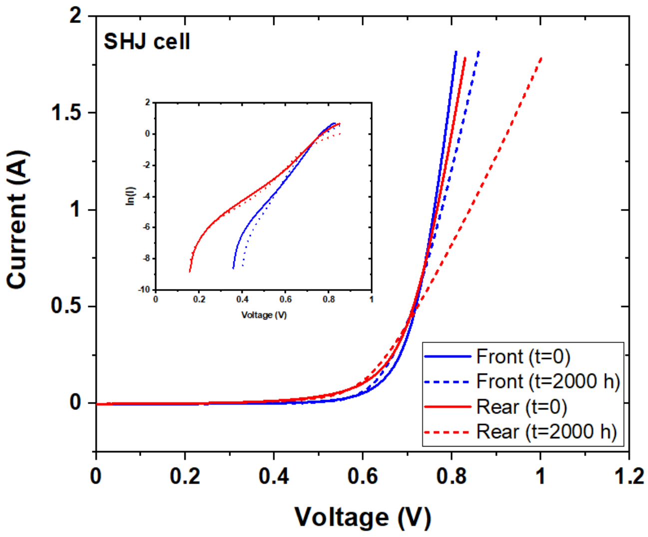
G/G-ES (EVA)



UV Exposure

- Rear-side more prone to degradation than front-side.
- Losses in **FF & V_{OC}** → defect generation at a-Si:H/c-Si interface.



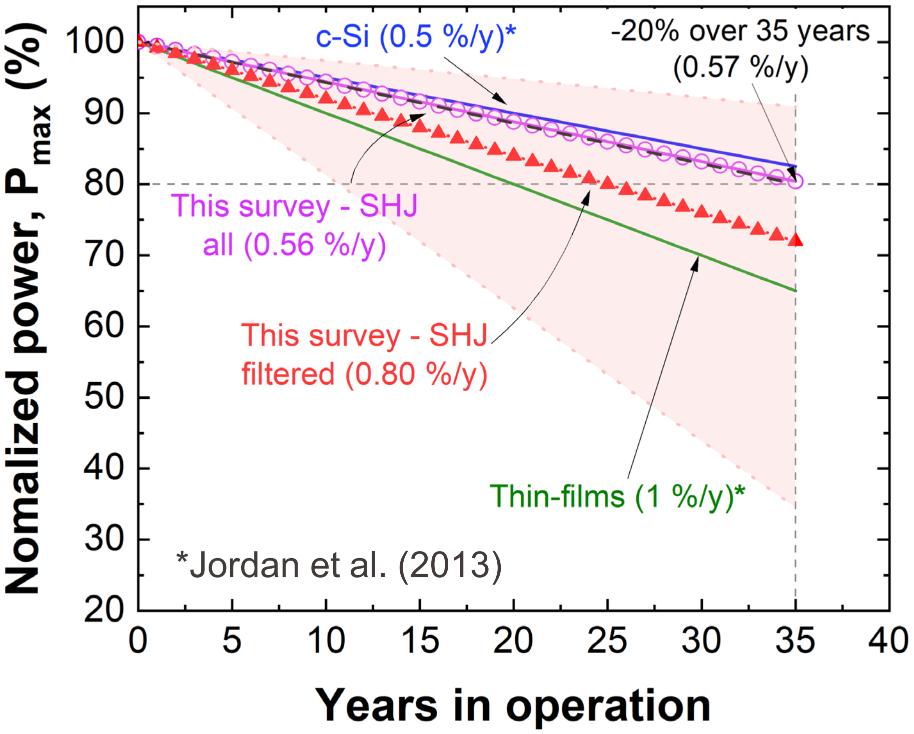


Sinha et al., EU PVSEC (2021)

- **Potential causes**: Si-H bond breakage*
  - Required energy ⟶ 3.5 eV (353 nm)

*Witteck et al., Prog. Photovolt. (2017)

How do we ensure the 35+ years of operation of SHJ modules?



Main issues of SHJ technology

Sensitivity to:
1. Moisture ingress
2. PID
3. UV exposure

Solutions:
- Use of **high volume resistivity encapsulants** (ionomer, PO).
- Prevent moisture ingress by using an **edge sealant**.
- Using encapsulants with **UV cut-off** or a cut-off **no lower than 353 nm** or use of **down-converters**.

Olatz Arriaga Arruti

EPFL

PV-lab IEM NEUCHATEL

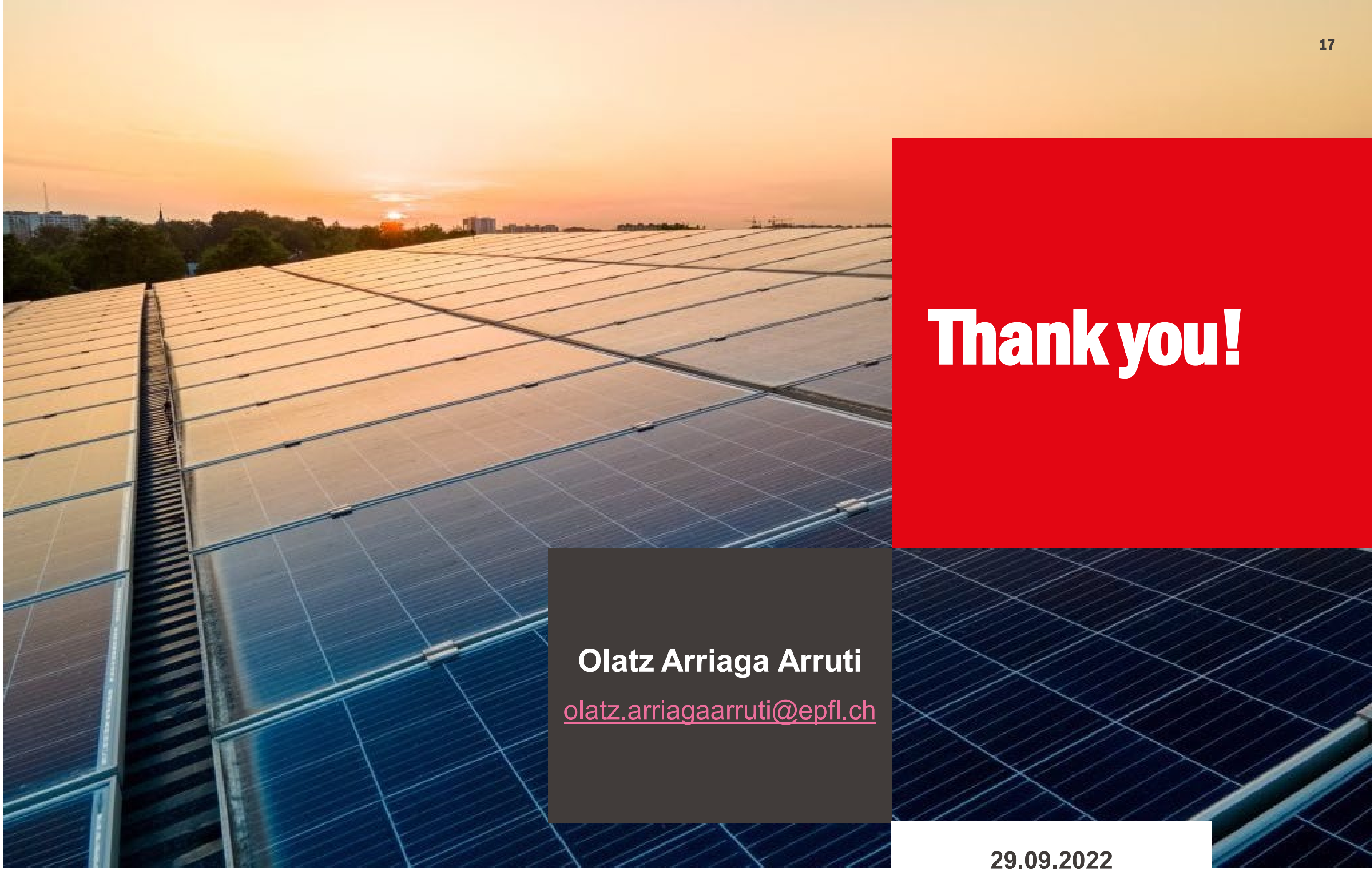
Outline

Conclusions

Olatz Arriaga Arruti

- **Literature review on long-term performance of SHJ modules**:
  - **PLR** values of **0.56 %/year** for all data-sets and 0.80 %/year for high-accuracy.
  - Main failure modes: loss in $\mathbf{V_{OC}}$ and **encapsulant discoloration**.
  - Could achieve lifetimes of 35+ years if encapsulated with a reliable BOM.

- **Indoor Accelerated Stress Tests:**
  - Sensitivity of SHJ cells & modules to **moisture ingress**, high voltages (**PID**) and **UV** exposure.
  - The use of an **edge sealant** is recommended to **reduce water ingress**: a dry EVA has proven to better mitigate SHJ DH and PID.
  - Modules encapsulated with **POEs** have also shown resistance to DH and PID, due to **low WVTR** and **high volume resistivity.**



Thank you!

Olatz Arriaga Arruti

olatz.arriagaarruti@epfl.ch

29.09.2022