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PECSYS Virtual Workshop
5th November 2020

WP 4: PV-EC systems based on low concentration and bifacial photovoltaics

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Workpackage objectives and main tasks

Objective: To develop a modular electrolyser consisting of one or several cells connected in series in a ‘cassette design’ to adapt the operating voltage of the EC- to the PV-modules. The area will be chosen, such that the LCHP are minimized (trade-off efficiency versus costs). The cassette design will be a reference to the integrated approaches

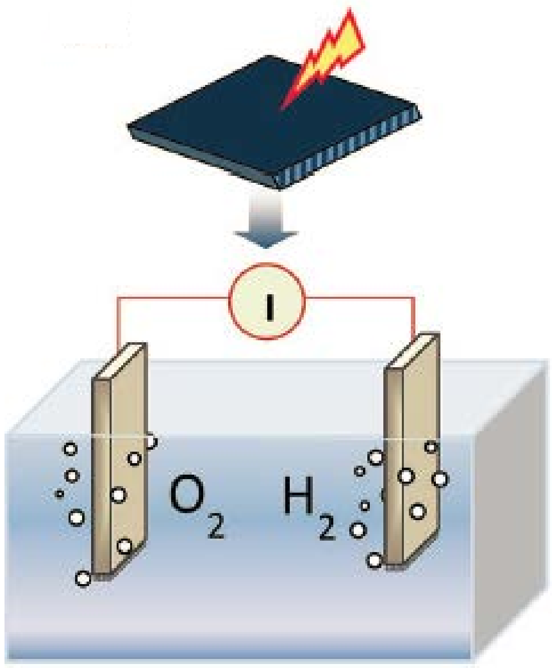
Task description
T 4.1 Serial Interface Definitions
T 4.2 10 - 30 cm^2 PEM electrolysis cell
T 4.3 10 - 30 cm^2 alkaline electrolysis cell
T 4.4 Proof of concept
T 4.5 Proof of concept low concentration

Explanation of the concept

“Cassette Design“ : Modular system with Photovoltaic + Electrochemical cell

PV: Silicon Heterojunction BIFACIAL Solar cell produced by EGP

EC: Proton Exchange Membrane (PEM) OR Alkaline electrolyser



Characteristic features of this approach:

- Modular design
- Direct coupling without DC/DC converters
- Specific cell design to get matching at PV maximum power point
- No batteries (fluctuating EC)
- Solar heating of both PV and EC

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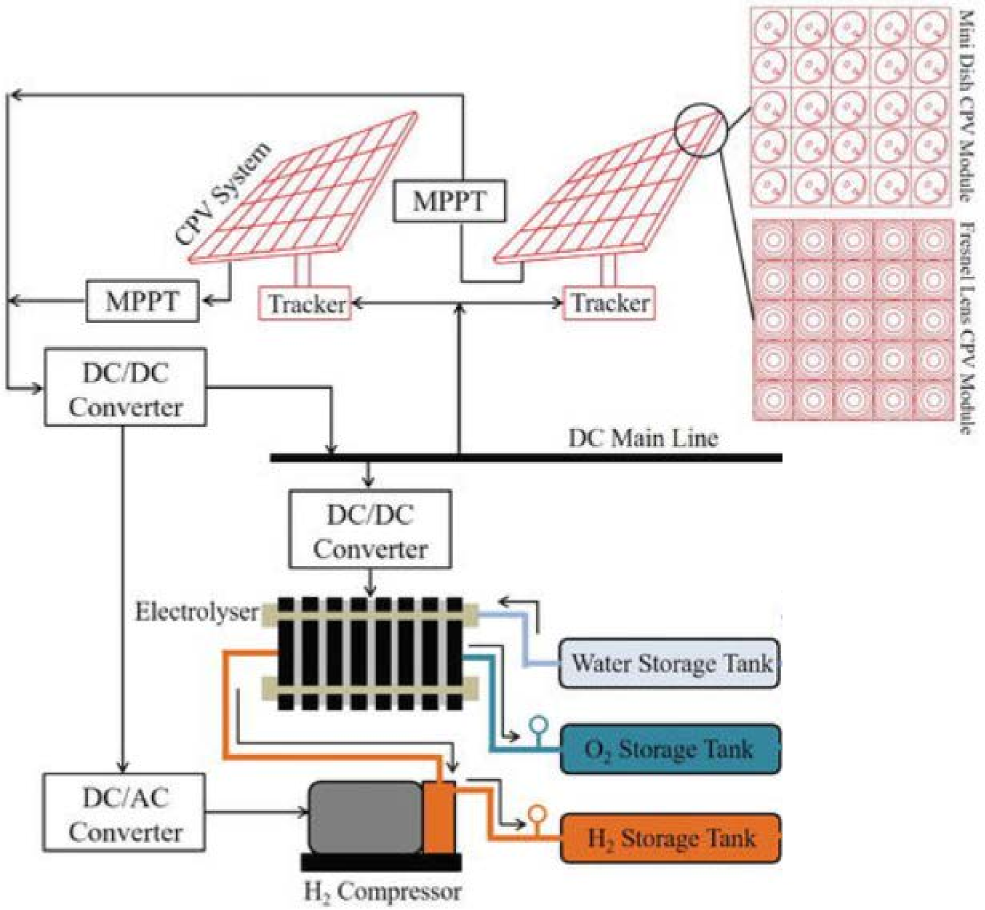
Explanation of the concept

Concentrated Photovoltaics



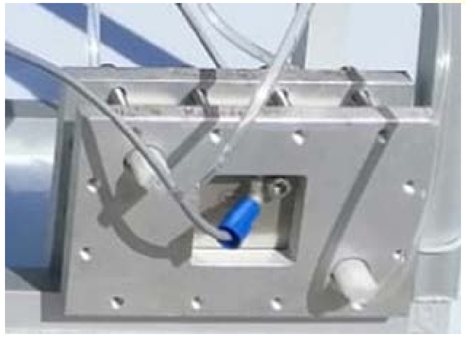
To reduce costs:

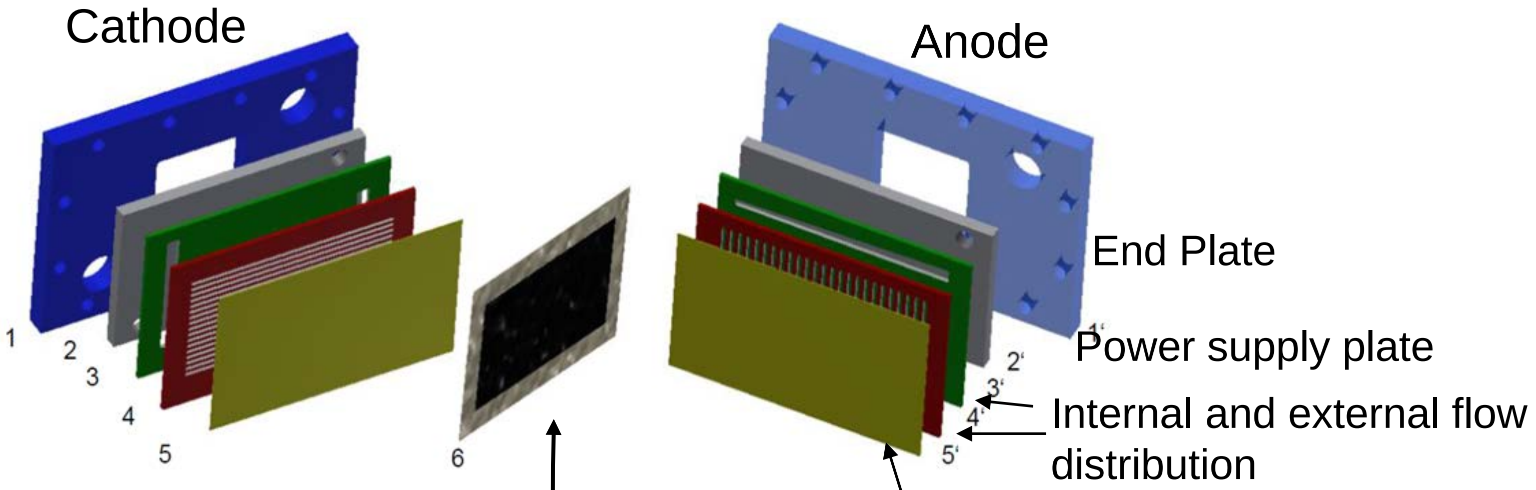
Low concentration ~ 2 SUN:
Low cost optics
No Pvcell cooling
Suitable for bifacial and SHJ cells
Possibility to use uniaxial tracker

Bifaciality
Excellent for SHJ cells
No Optics
No Tracker

ELECTROCHEMICAL CELL: PROTON EXCHANGE MEMBRANE

- **PEM electrolysis cell Developed in Task 4.2 at FZJ**
- Nafion membrane
- Reduced amount of noble catalysts (-80%)



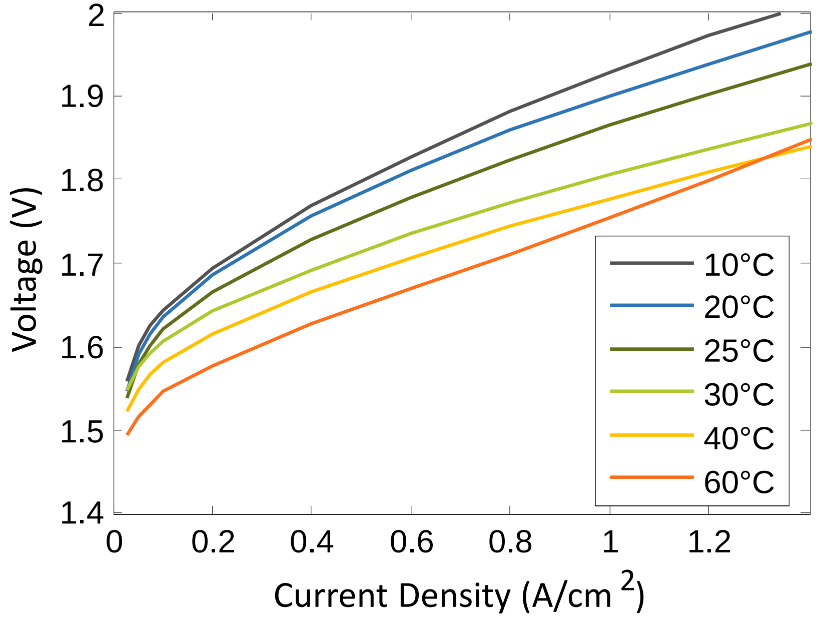


Pt
0.13 mg/cm^2

IrO_2
0.38 mg/cm^2

Conductive diffusion layer

Nafion 212 catalyst coated membrane



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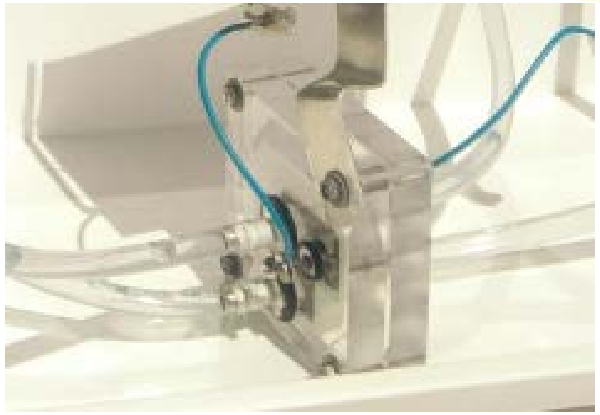
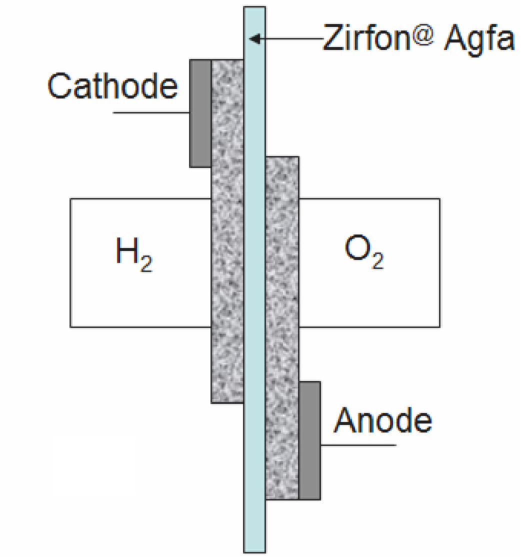
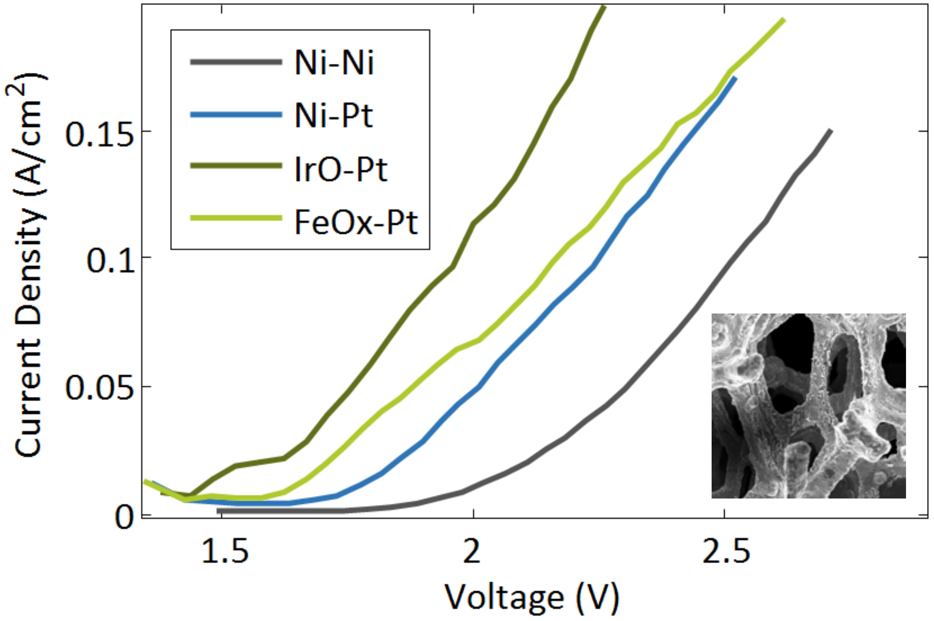
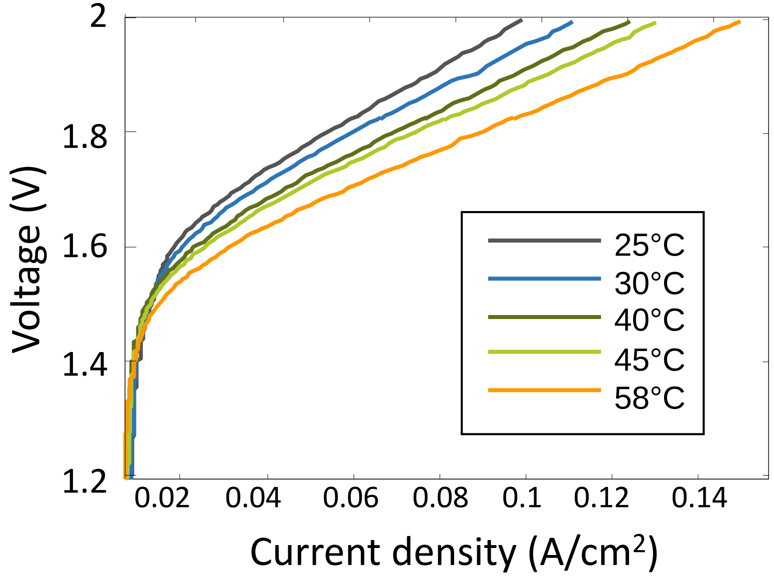
ELECTROCHEMICAL CELL: ALKALINE CELL

- **16 cm^2 Alkaline cell Developed in Task 4.3 at CNR**
- Zero gap approach with Zirfon@ membrane
- 1M KOH, PMMA case
- Ni foam electrodes functionalised by electroless deposition: 0.015 mg/cm^2 Pt at the cathode









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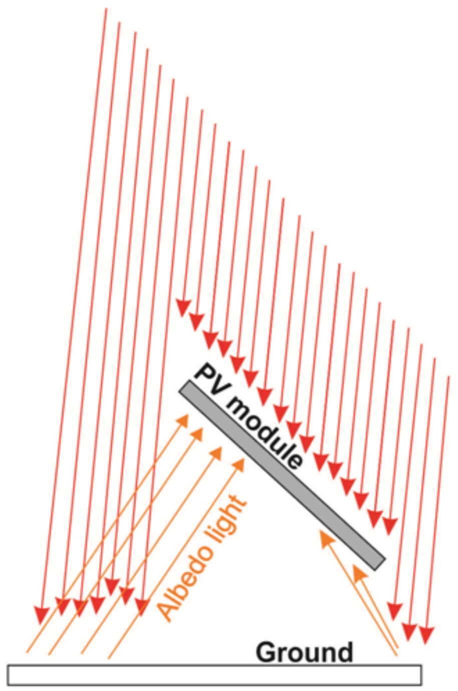
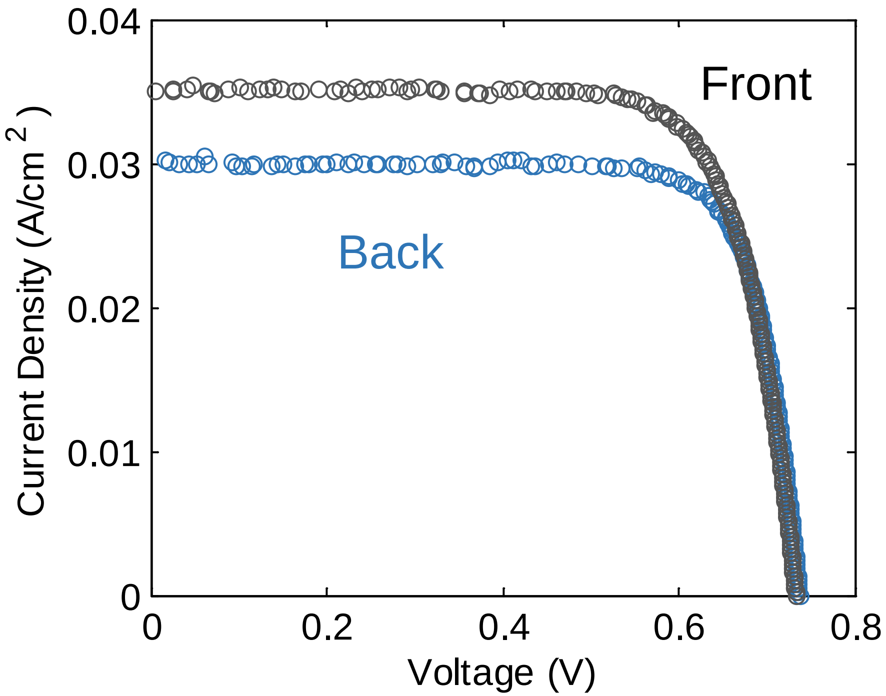
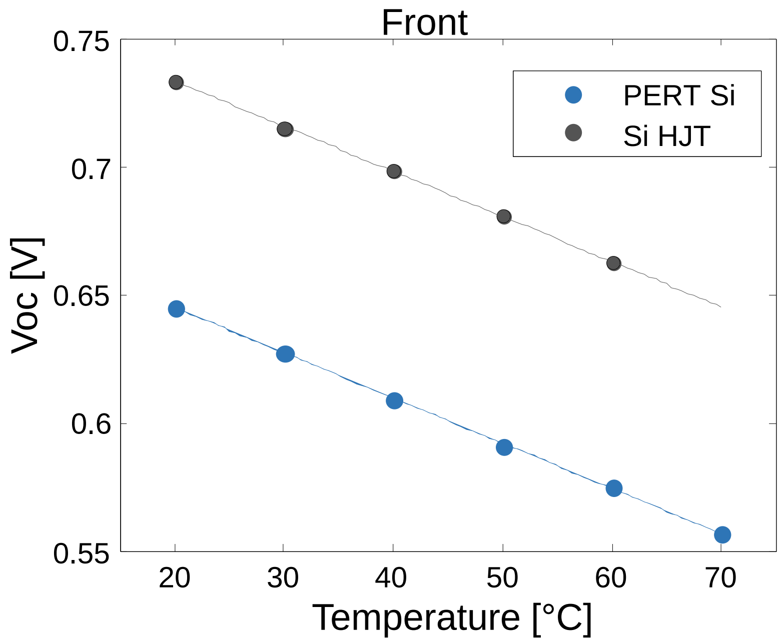
Silicon Heterojunction bifacial solar cell

- **Proof of concept cassette approach Task 4.4**
- SHJ solar cell produced by EGP
- Higher V_{oc} (0.73 V) and lower temperature dependence, compared to PERT Si cells



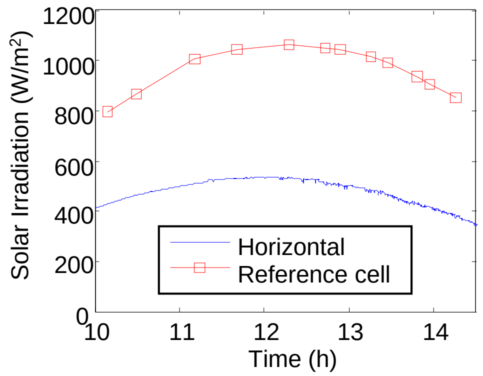


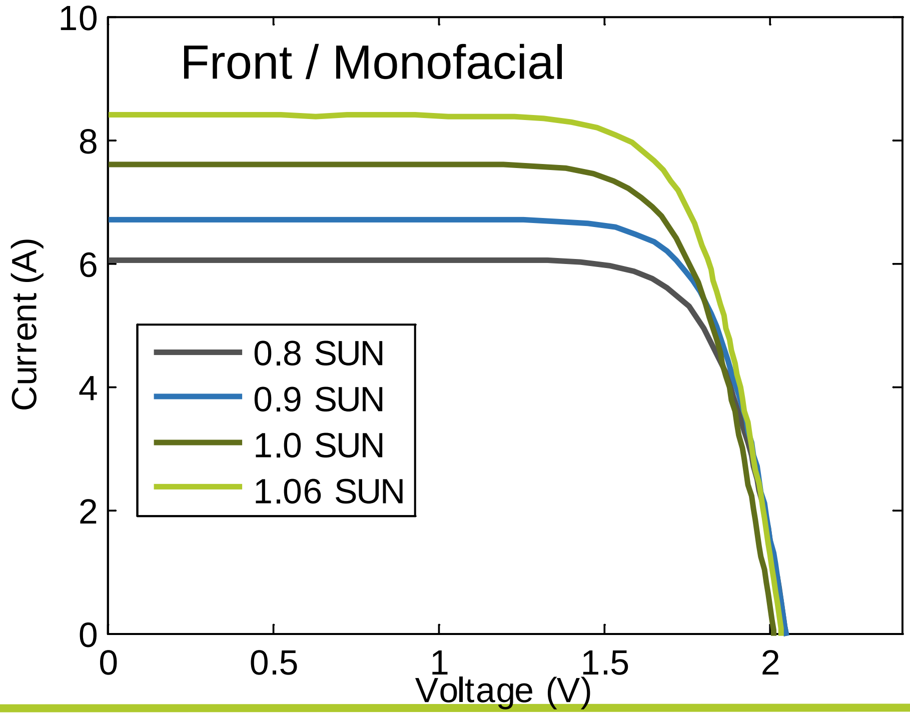


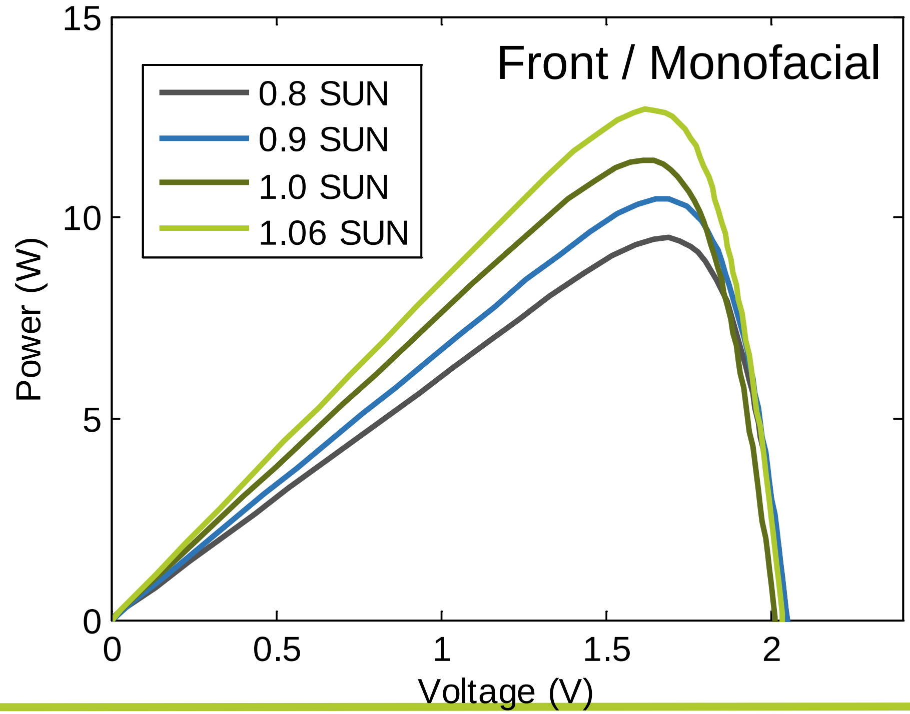
Silicon Heterojunction mini-module

- 3 cells connected in series by copper ribbons
- PV area 230 cm^2
- Ultra light module: lamination in a transparent EVA-backed polyethylene double substrate

OUTDOOR







V_{OC} = 2.19 V

η_{PV} 16.4 %

STH = 1.23 I η_F/ ($Area_{PV} P_{in}$)

13.7%
Maximum Achievable STH
In Monofacial mode
@ 1 SUN

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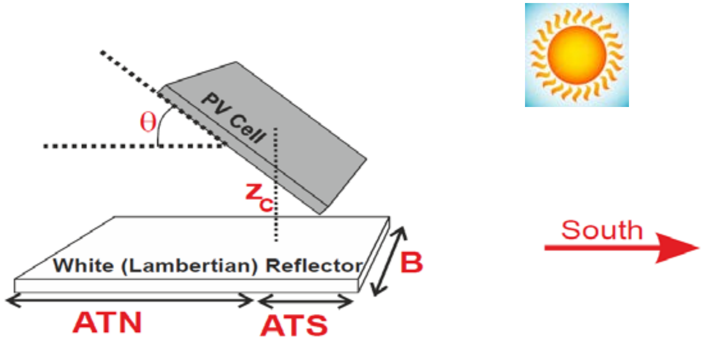
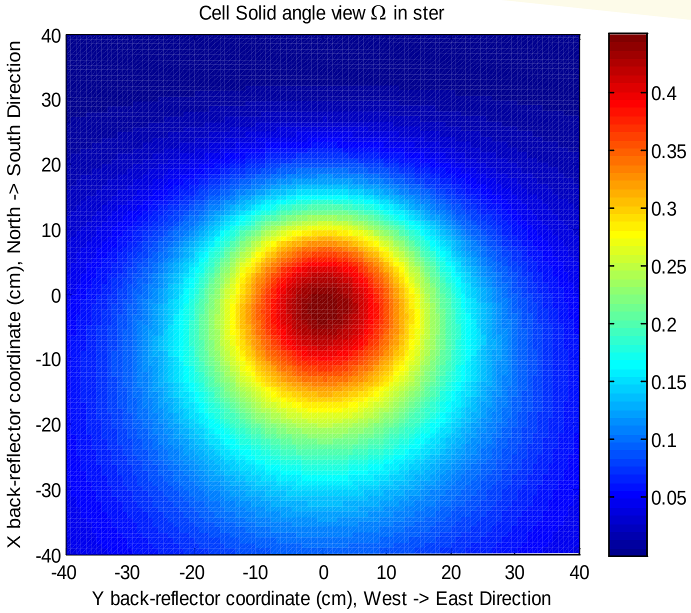
Proof of concept using Bifaciality: System Optimization

- Developement of a model to optimize bifaciality



$$I = I_{SC}^{F} + I_{SC}^{R} - I_0\left(e^{\frac{qV_i}{nKT}} - 1\right)$$

$$V = V_i - R_S I$$



$$I_{SC}^{F} = A \int_{\lambda_{Gap}}^{0} EQE_f(\lambda) \cdot ISSx(\lambda) \cdot d\lambda$$

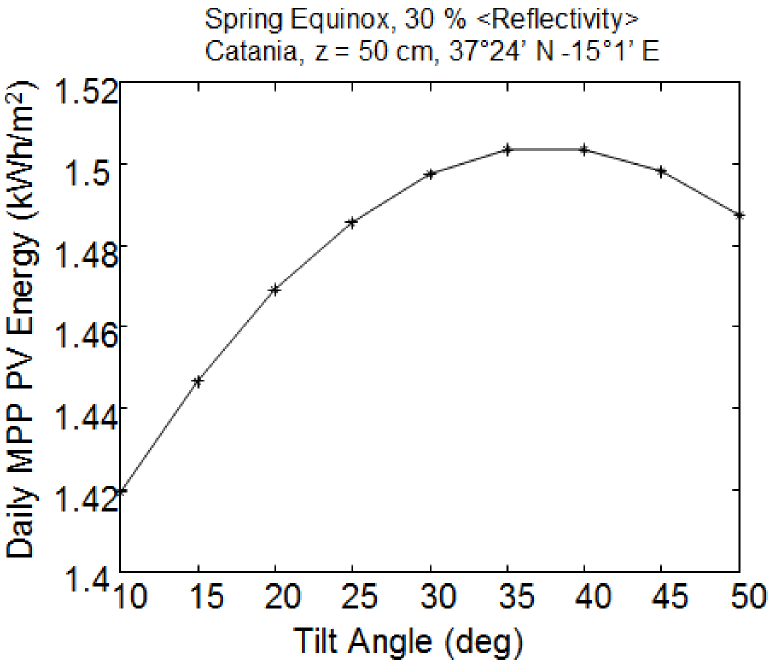
$$I_{SC}^{R} = \iint_{\Sigma} (\Omega(x,y) / 2\pi) \cdot fs(x,y) \cdot dxdy \quad \times \int_{\lambda_{Gap}}^{0} albedo(\lambda) \cdot EQE_b(\lambda) \cdot HSSx(\lambda) \cdot d\lambda$$

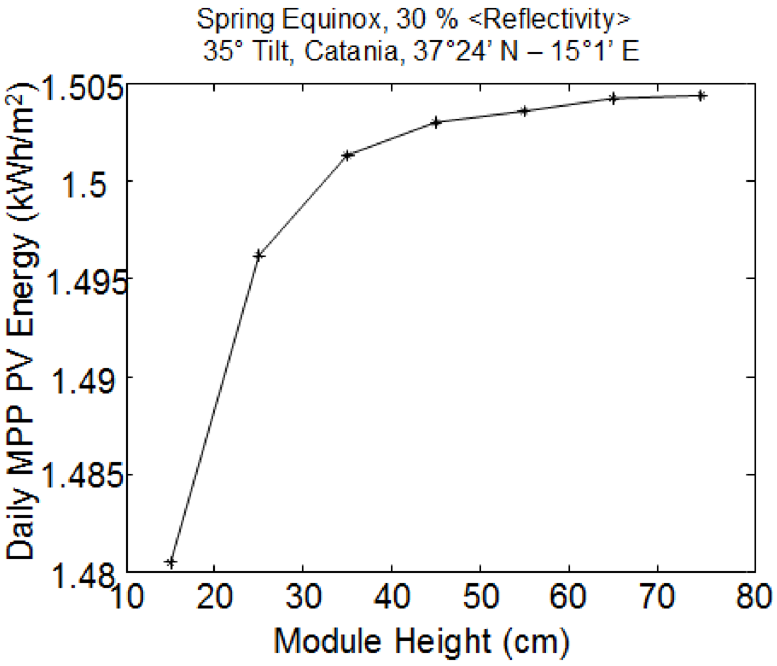
$$t = t_{amb.} + (NOCT - 20) \cdot \frac{G_{f,r}}{800} \; ; \qquad T = t + 273.15$$

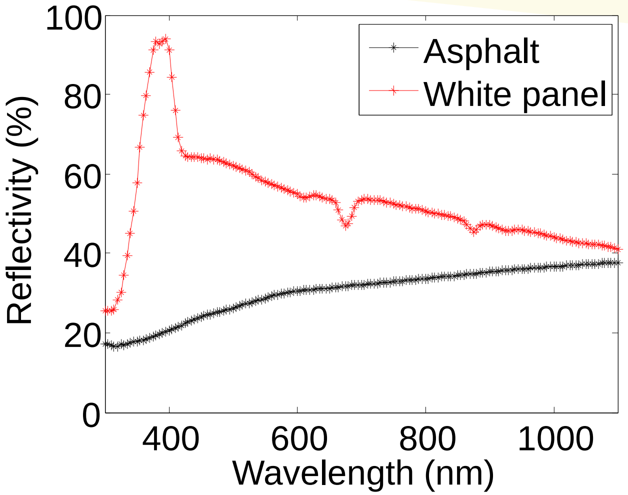
Fabio Ricco Galluzzo, Andrea Canino, Cosimo Gerardi, Salvatore A Lombardo,
A new model for predicting bifacial PV modules performance: first validation results, 2019 IEEE 46th Photovoltaic Specialists Conference (PVSC) [IEEE], Pages: 1293-1297

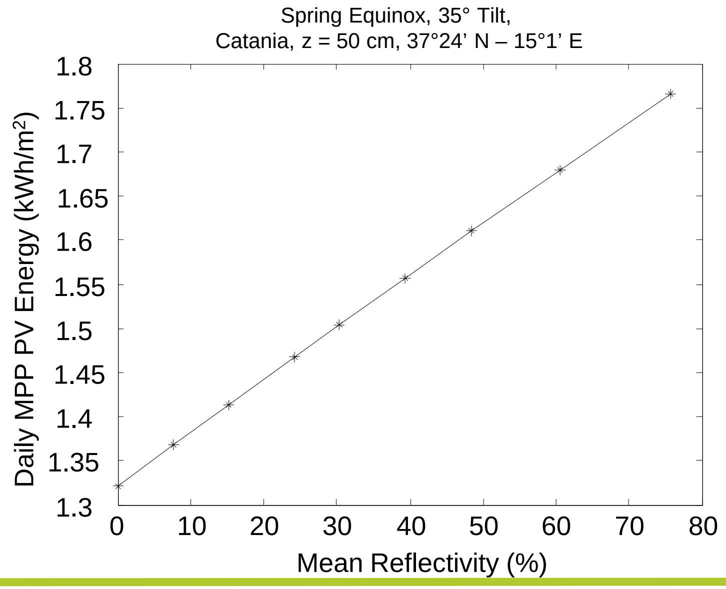
Proof of concept using Bifaciality: System Optimization

- Model Results
- Experimental validation with landscape orientation



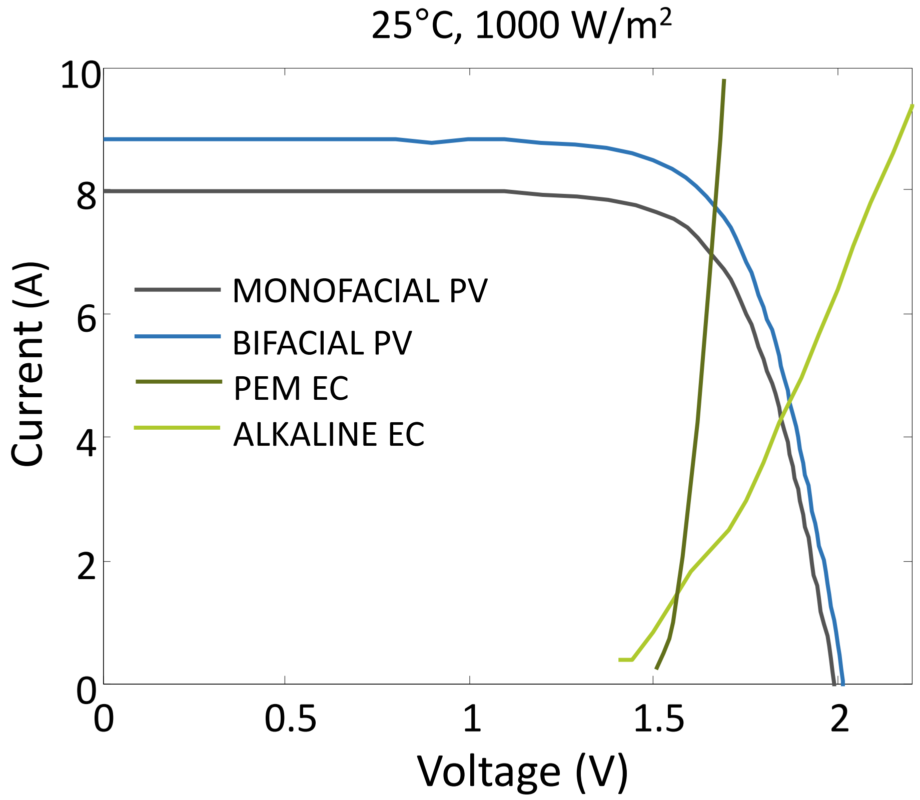


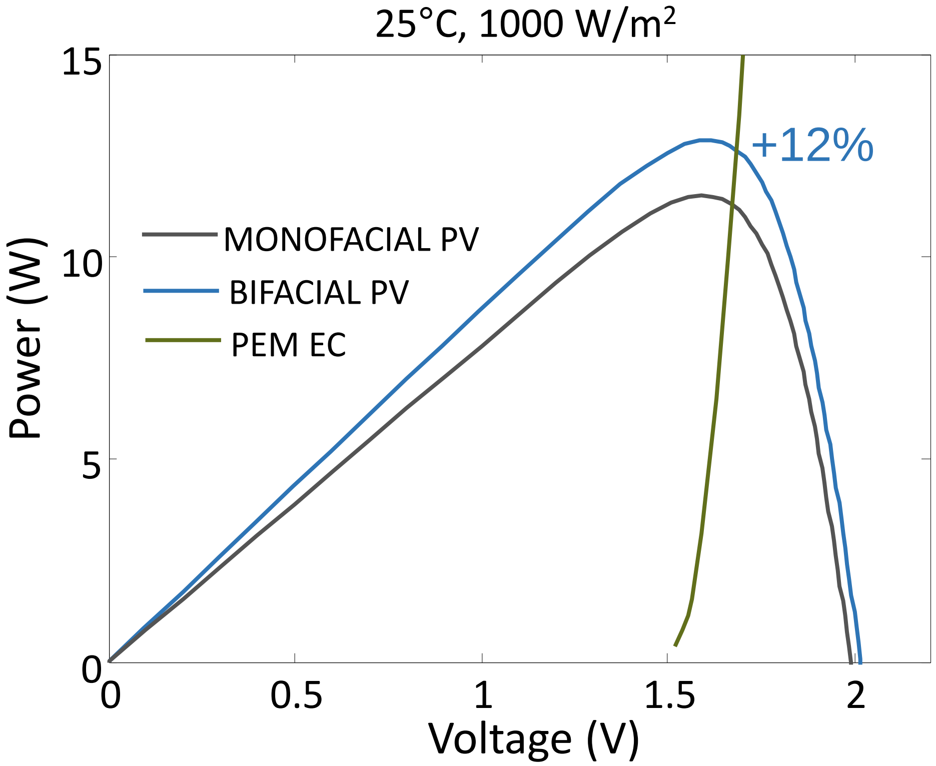




Silicon Heterojunction bifacial mini-module

- Bifaciality optimised by 35° Tilt angle, 50 cm module height, landscape orientation
- 12% increase of maximum power in bifacial mode compared to monofacial





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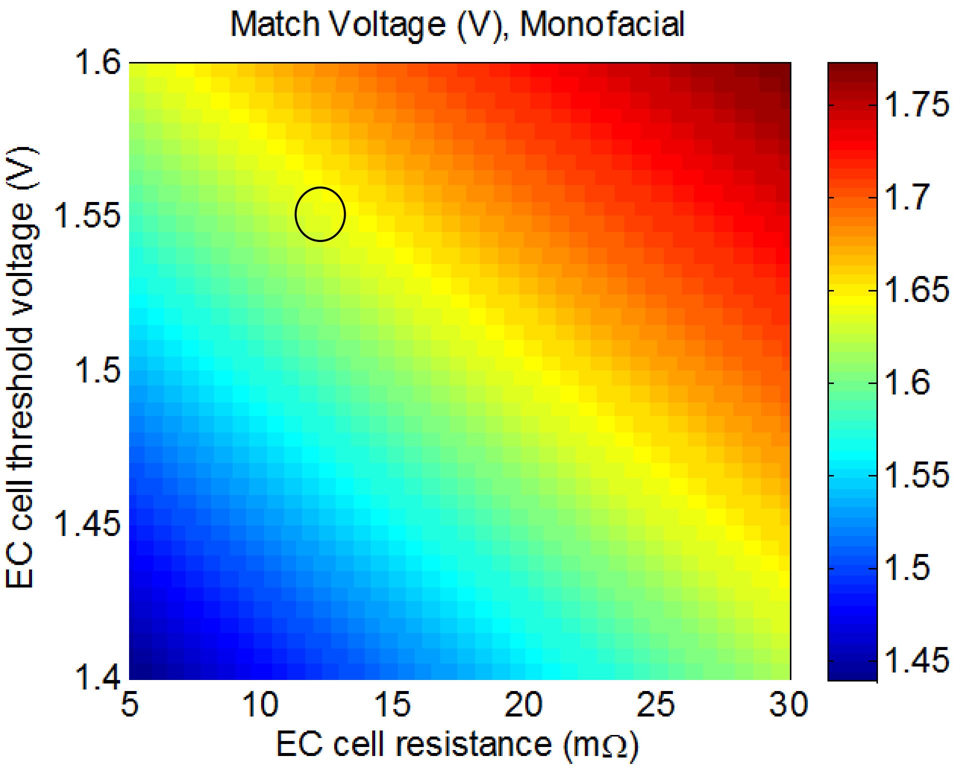
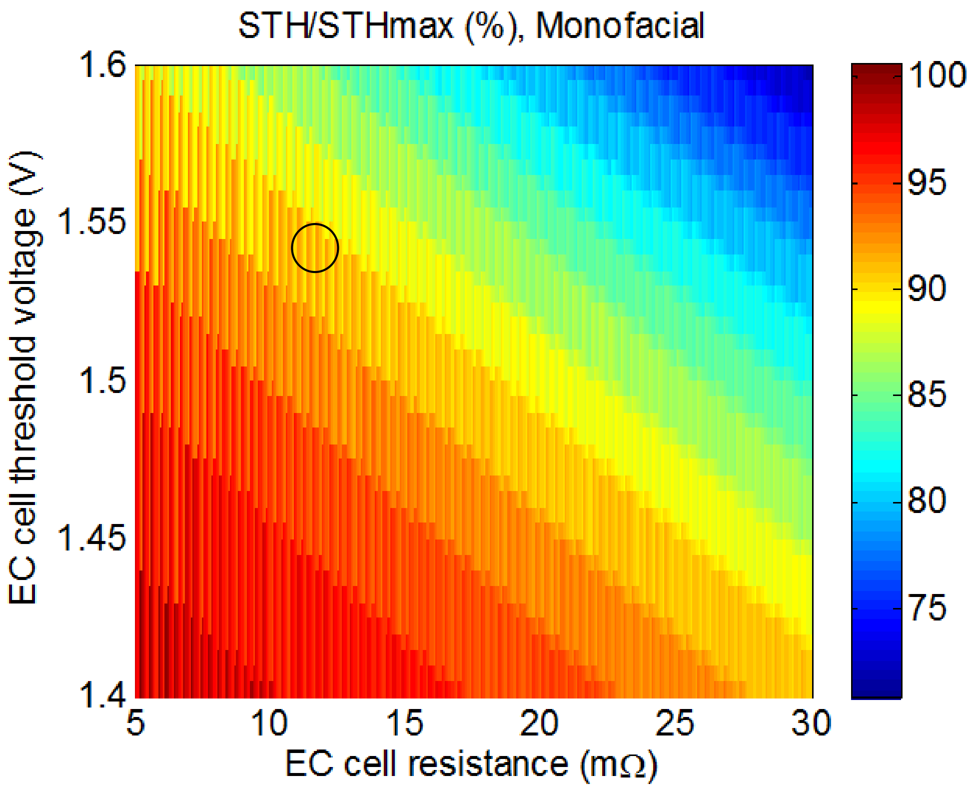
Silicon Heterojunction mini-module: coupling to the EC

$$V_{match} = V_{TH} + R_{EC} I_{match}$$



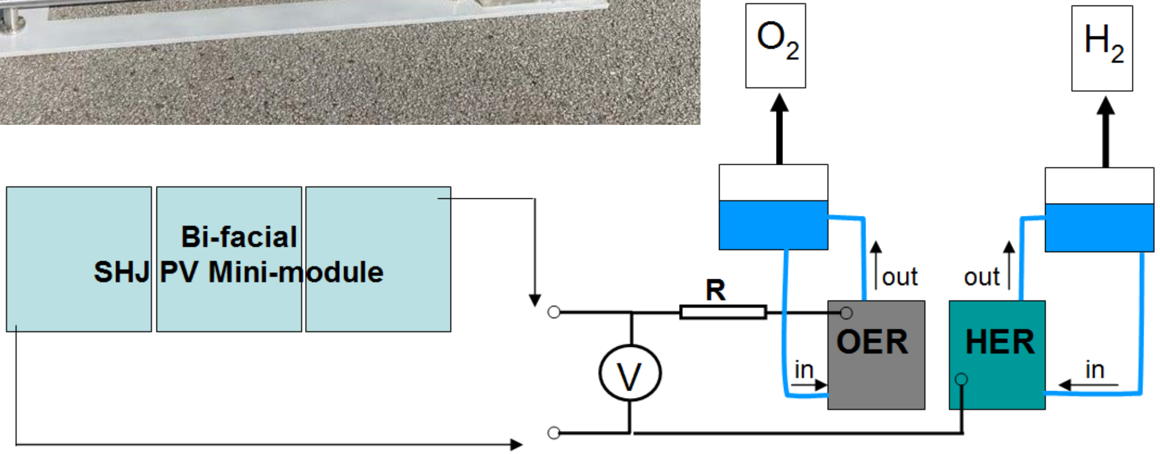


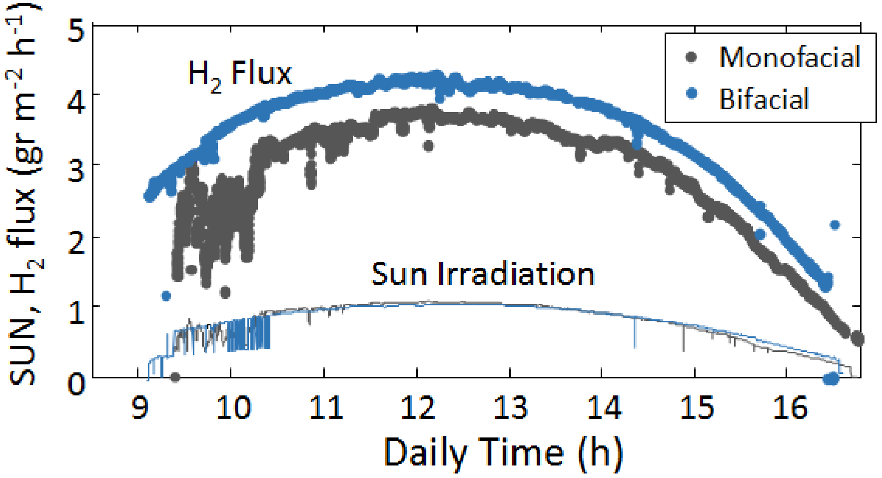
PEM: Expected STH 90% of the STHmax ~ 12%

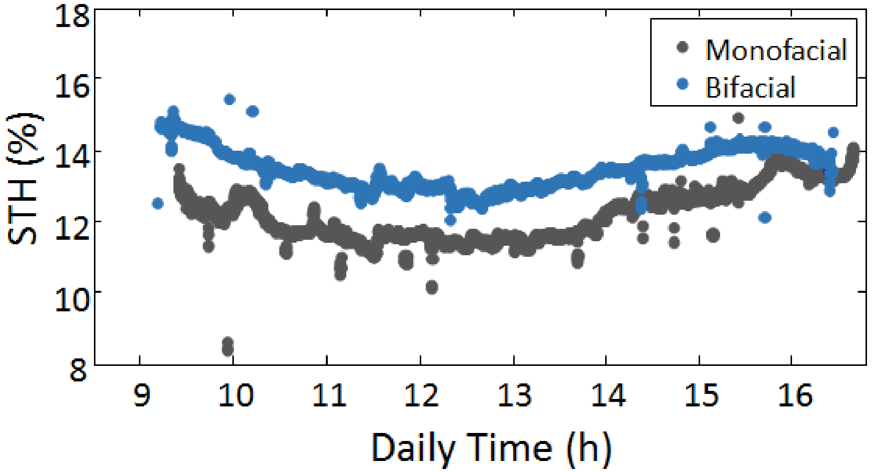
Alkaline: Expected STH 50% of the STHmax ~ 7%

Cassette approach Proof of concept using Bifaciality

- PEM electrolyzer: Increase of H_2 flux from 3.7 gr/m^2/h (monofacial) to 4.2 gr/m^2/h
  Average STH 11.55 % in monofacial, 13.5% in bifacial mode

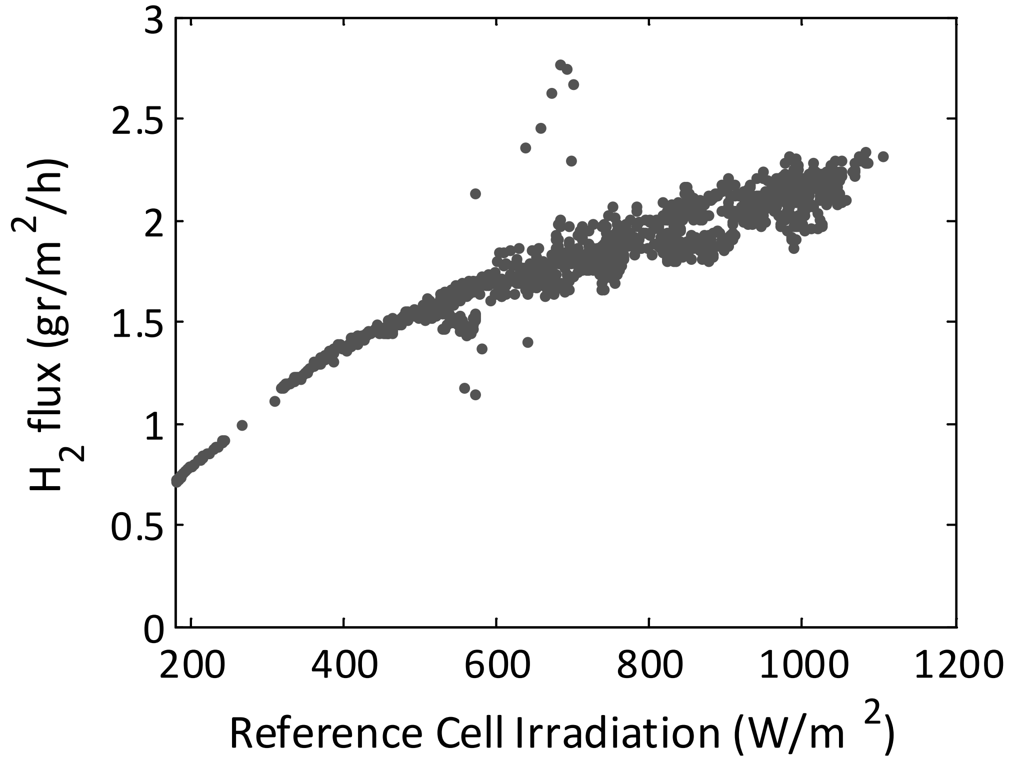


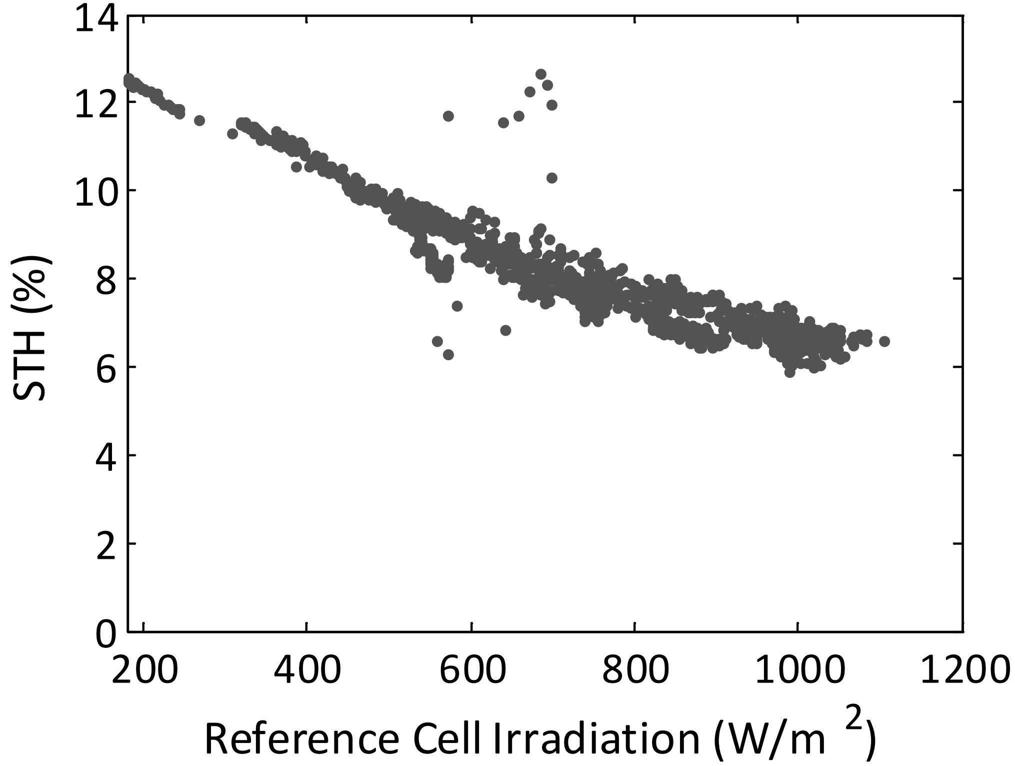




Cassette approach Proof of concept using Bifaciality

- Alkaline electrolyzer : Average H_2 flux 1.8 gr/m^2/h
- Average STH 9% in bifacial mode
- Values in line with PECSYS objectives: STH > 6% ; flux > 1.6 gr/m^2/h





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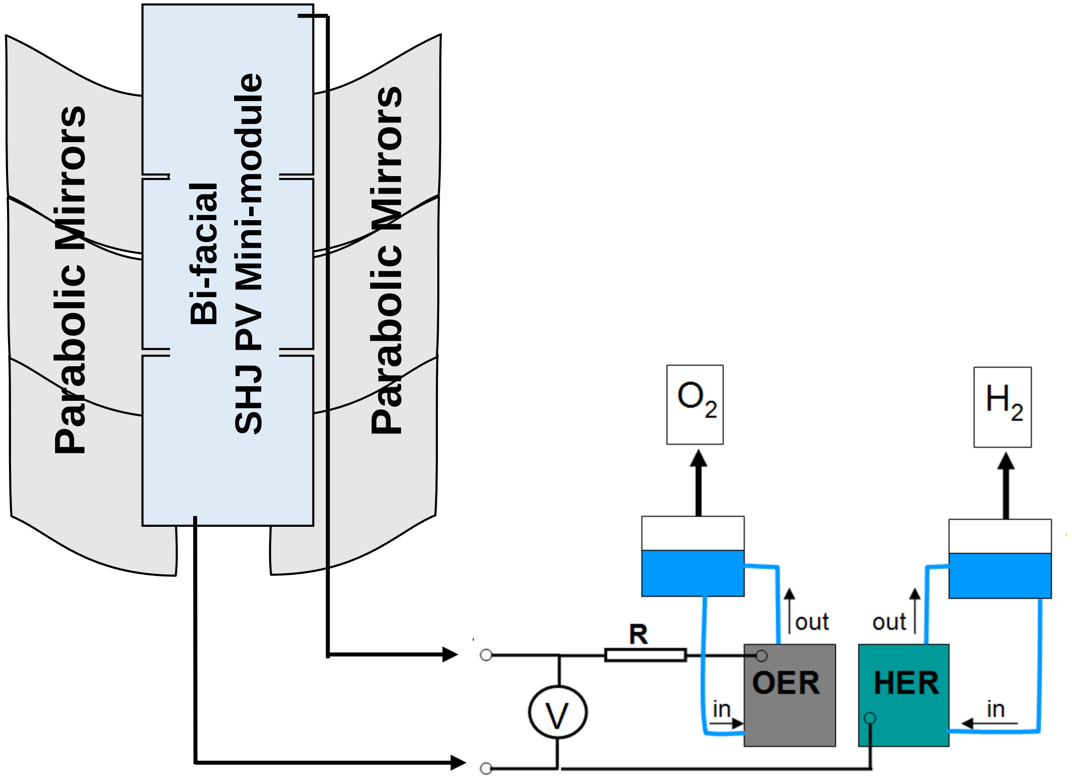
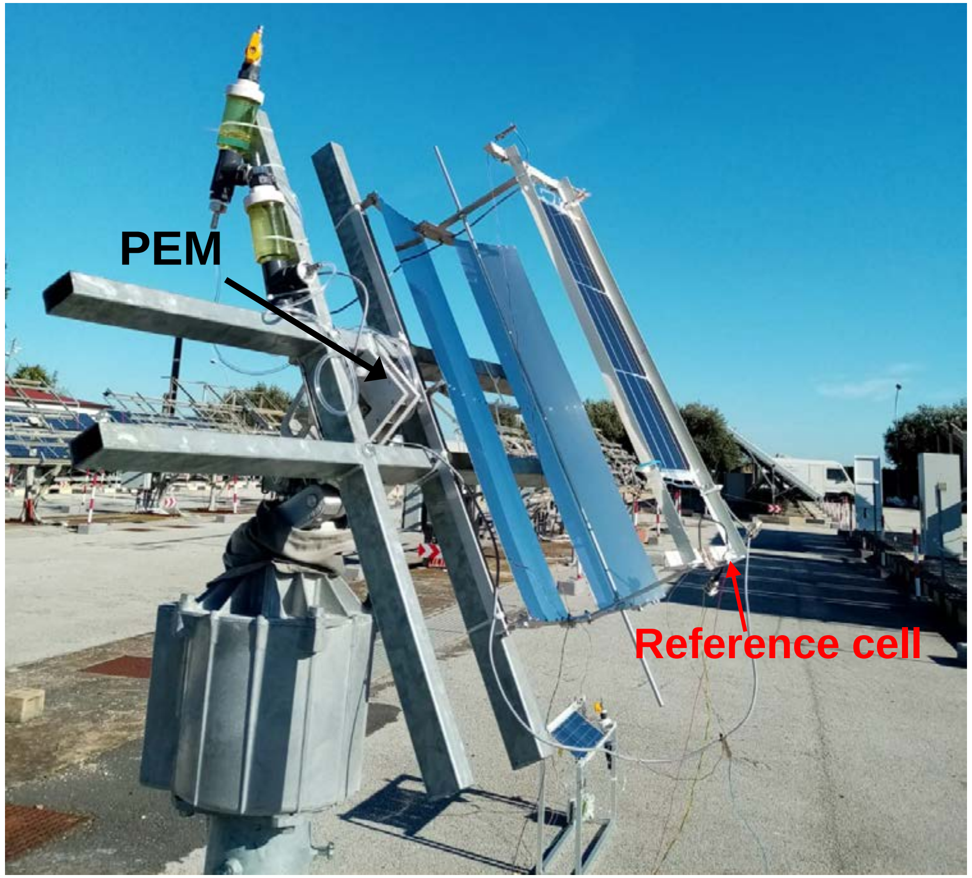
Low Concentration Proof of concept

- **Proof of concept Low Concentration Task 4.5**
- Mirrors on the back, design and fabrication at CNR
- Total area including mirrors 0.12 m^2





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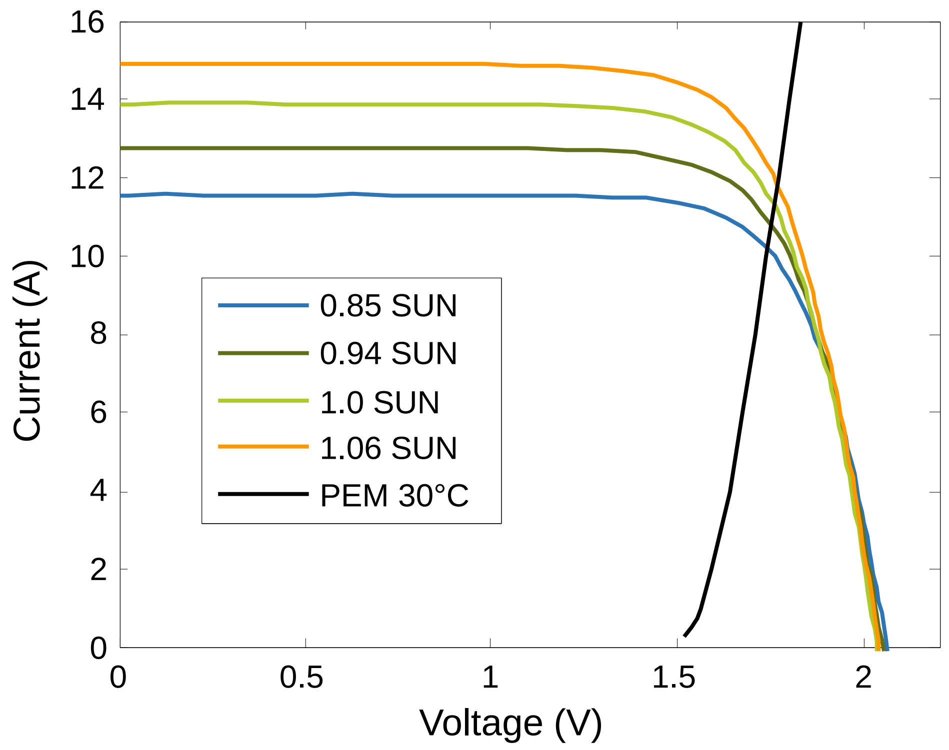
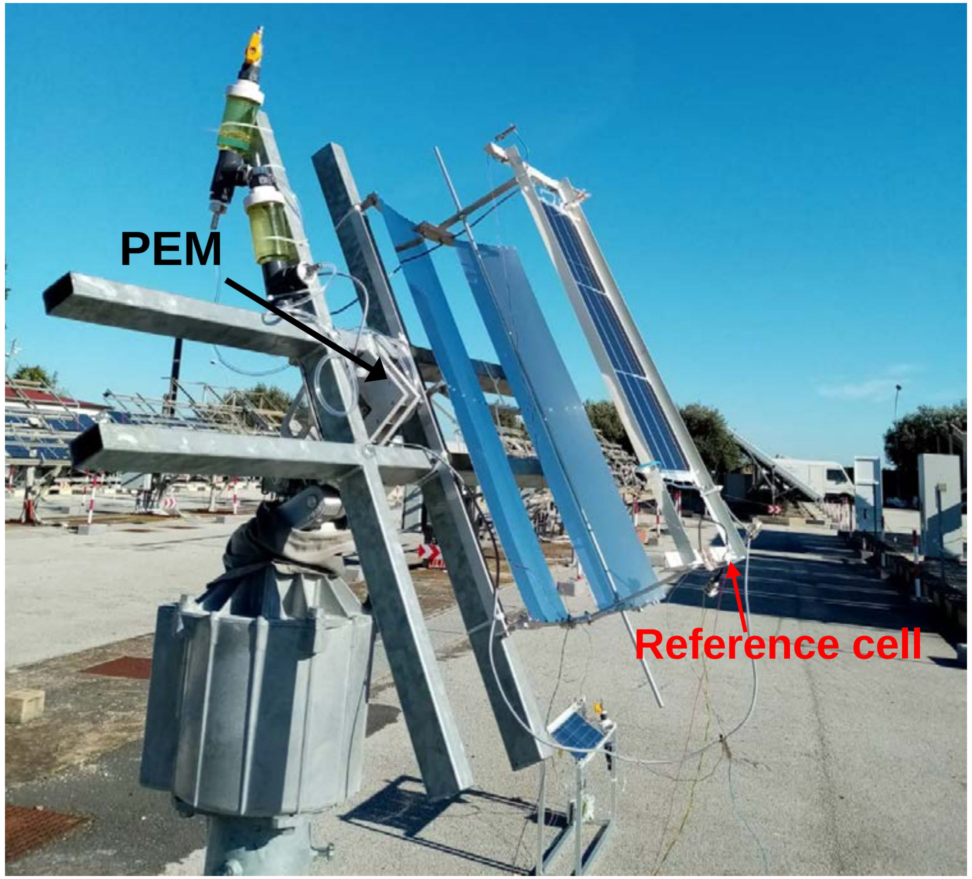
Low Concentration Proof of concept

- Concentration factor 1.63





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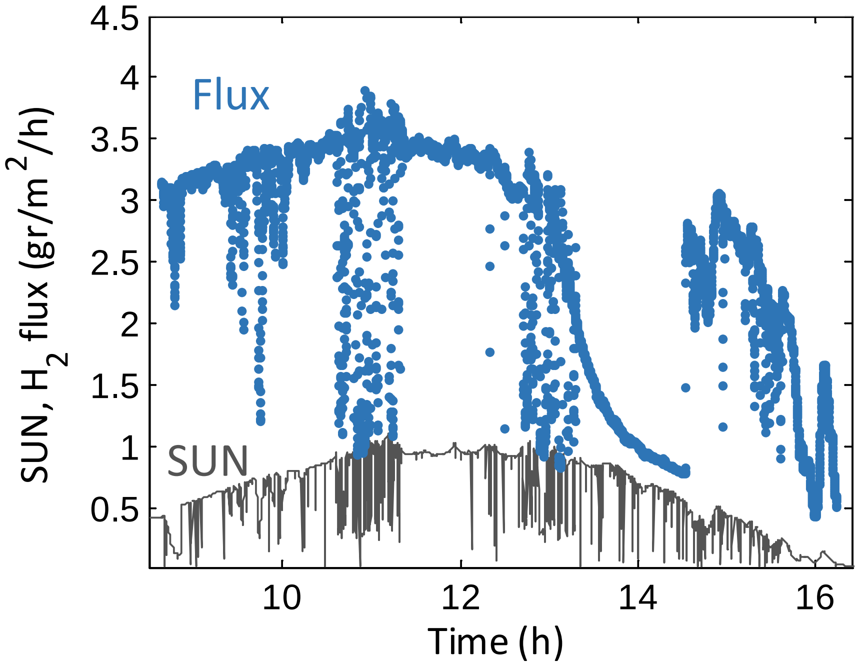
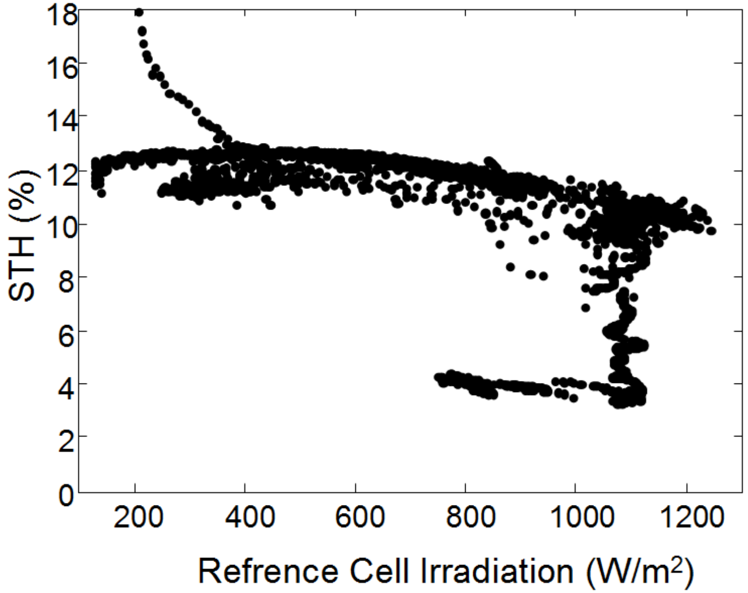
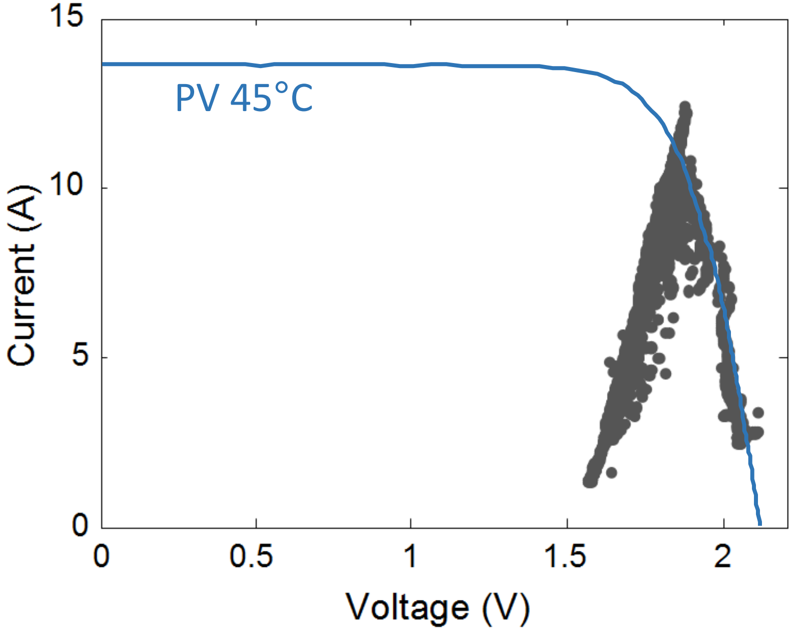
Low Concentration Proof of concept

- Average STH = 10%
- Average H_2 flux 2.48 gr /m^2/h (total area including mirrors); 3.94 gr /m^2/h (PVcells area)







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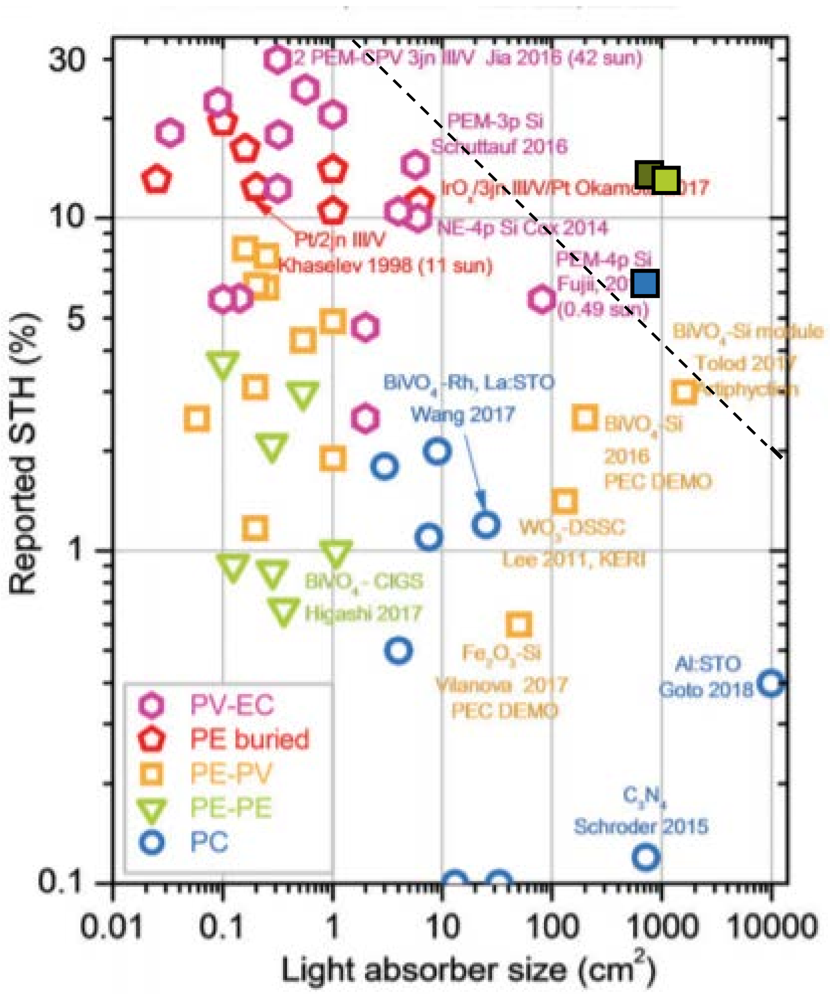
Progress beyond state of the art and impact

- Comparison between Various Cassette approach systems in PECSYS and state of the art



- SHJ Bifacial + Alkaline 730 cm²
- SHJ Bifacial + PEM 730 cm²
- SHJ Bifacial Low Conc + PEM 0.1 m²

- Both the developed systems in monofacial configuration perform well compared to data reported in literature

- Both the developed systems in BIFACIAL and LOW CONC configuration perform better than literature data

* J.Y. Kim et al. Chem. Soc. Rev. (2019) 48, 1908

Progress beyond state of the art and impact

- The bifacial configuration is very promising, since it allows 13% increase of produced hydrogen while keeping the same costs of a monofacial system

	PV Area (m^2)	PV Efficiency (%)	Average STH (%)	H_2 flux gr/m^2/h
HCPV*	1	30	18.7	**4.2 - 5.35**
Monofacial (PECSYS)	0.073	16.4	11.55	3.7
Bifacial (PECSYS)	0.073	16.4	13.5	**4.2**
LCPV (PECSYS 1.63 sun)	0.12	18.4	10	2.48 - 3.94

- Best performing SHJ cells can reach up to 26% efficiency, therefore further STH improvement may be expected

* S. Muhammad-Bashir et al. Solar Energy 205 (2020) 461–464

Publications and conference presentations

- SMS Privitera, M Muller, W Zwaygardt, M Carmo, RG Milazzo, P Zani, M Leonardi, F Maita, A Canino, M Foti, F Bizzarri, C Gerardi, SA Lombardo Highly efficient solar hydrogen production through the use of bifacial photovoltaics and membrane electrolysis. Journal of Power Sources 2020, 273, 228619;

- Dipanjan Sengupta, Stefania MS Privitera, Rachela Gabriella Milazzo, Corrado Bongiorno, Silvia Scalese, Salvatore Lombardo, Ni foam electrode solution impregnated with Ni-Fe X (OH) Y catalysts for efficient oxygen evolution reaction in alkaline electrolyzers, RSC Advances 2020, 10(43), 25426 ;

- Rachela G Milazzo, Stefania Privitera, Silvia Scalese, Salvatore A Lombardo , Effect of Morphology and Mechanical Stability of Nanometric Platinum Layer on Nickel Foam for Hydrogen Evolution Reaction, Energies, 2019, 12(16) 3116;

- S Filice, G Urzì, RG Milazzo, SMS Privitera, SA Lombardo, G Compagnini, S Scalese, Applicability of a New Sulfonated Pentablock Copolymer Membrane and Modified Gas Diffusion Layers for Low-Cost Water Splitting Processes, Energies, 2019, 12(11) 2065;

- Rachela G Milazzo, Stefania MS Privitera, Daniele D'Angelo, Silvia Scalese, Salvatore Di Franco, Francesco Maita, Salvatore Lombardo, Spontaneous galvanic displacement of Pt nanostructures on nickel foam: Synthesis, characterization and use for hydrogen evolution reaction, International Journal of Hydrogen Energy 2018, 43(16) 7903.

Conclusions and Outlook

- Alkaline and PEM electrolyzers suitable for direct connection to PV modules have been developed.

- Modular PV-EC systems have been built without DC/DC converter, employing a mini module of 3 SHJ solar cells

- The effect of low concentration and bifaciality has been evaluated through outdoor testing in Catania, Italy, and compared to the standard monofacial PV operation

- The best PV-EC matching is achieved by employing a PEM electrolyser and the SHJ PV module operating in bifacial configuration (4.2 gr $H_2/m^2/h$ and STH 13.5%)

- Bifaciality represents the most promising method to improve STH and to produce high hydrogen flux while mantaining the same costs of standard monofacial solar cells

Thank you for your attention!

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