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PECSYS Virtual Workshop
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WP 7: 10m² outdoor PV-EC test field

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(**Forschungszentrum Jülich**, DE)

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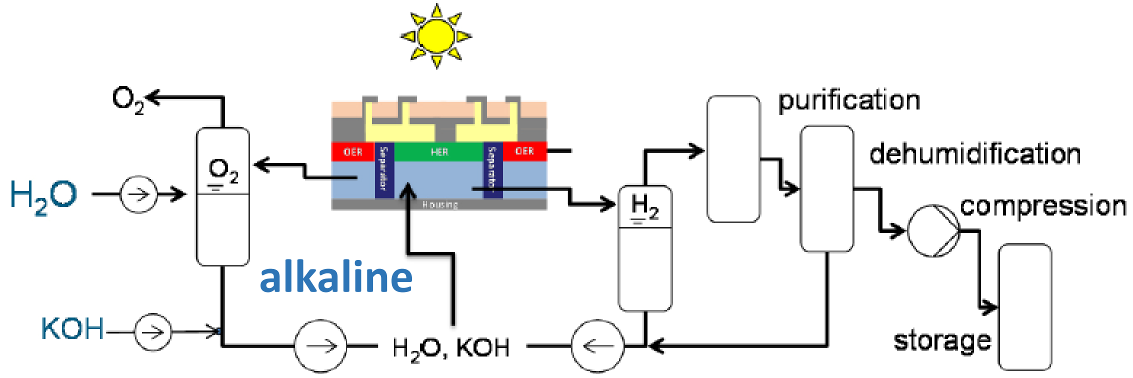
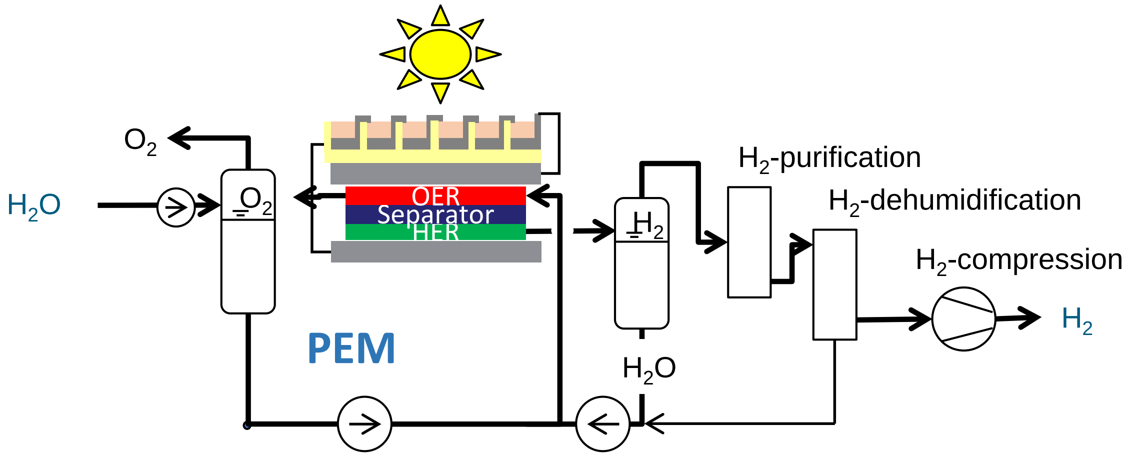
Workpackage objectives and main tasks

Objective: To scale up the selected device concept to the module size and the actual realization and testing of the 10 m² system including Balance of Plant and gas handling

Task description
T 7.1 Concept for test field, balance of plant, gas handling and safety
T 7.2 Procure necessary hard ware and select test field
T 7.3 Concepts for fabrication of components for 10 m² system
T 7.4 Realization of modules for 10 m^2 system
T 7.5 Realisation of 10 m^2 system and testing
T 7.6 Large area characterization of prototype panels and demonstrator panels

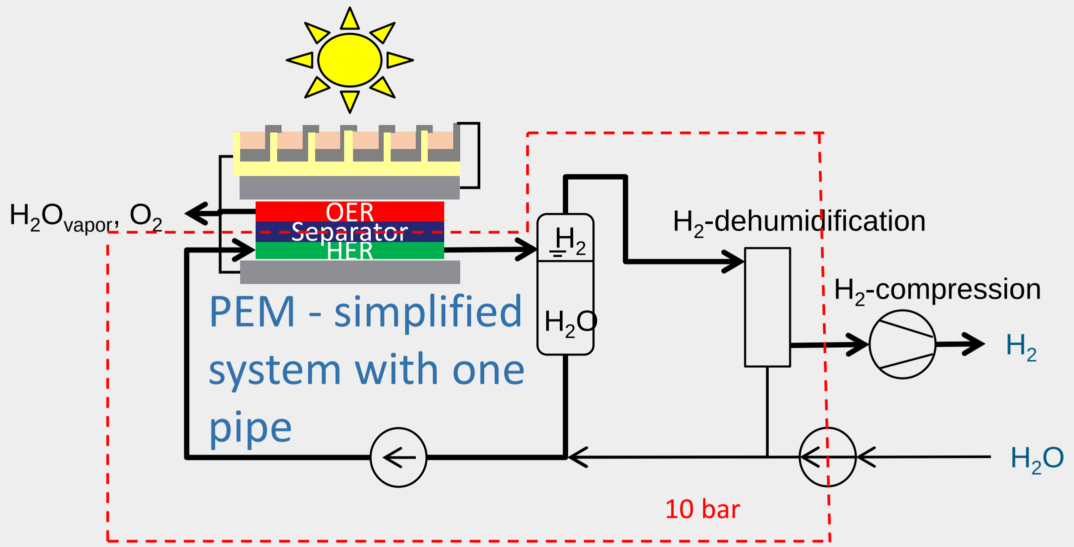
Explanation of the concept – electrolysis & PV





Advanced PEM electrolysis system

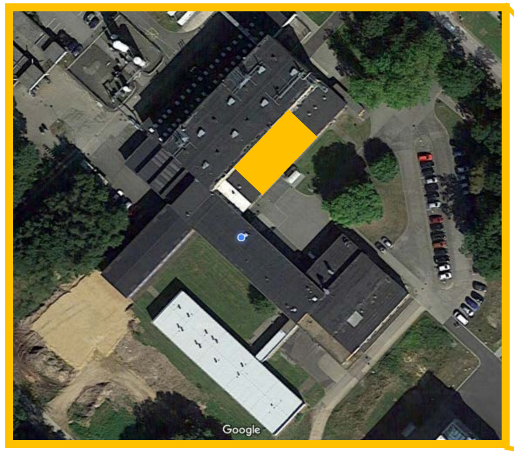
- Non toxic or corrosive media
- Slightly pressurized operation possible
- Only one pipe necessary
- Formation of explosive gas mixtures not critical

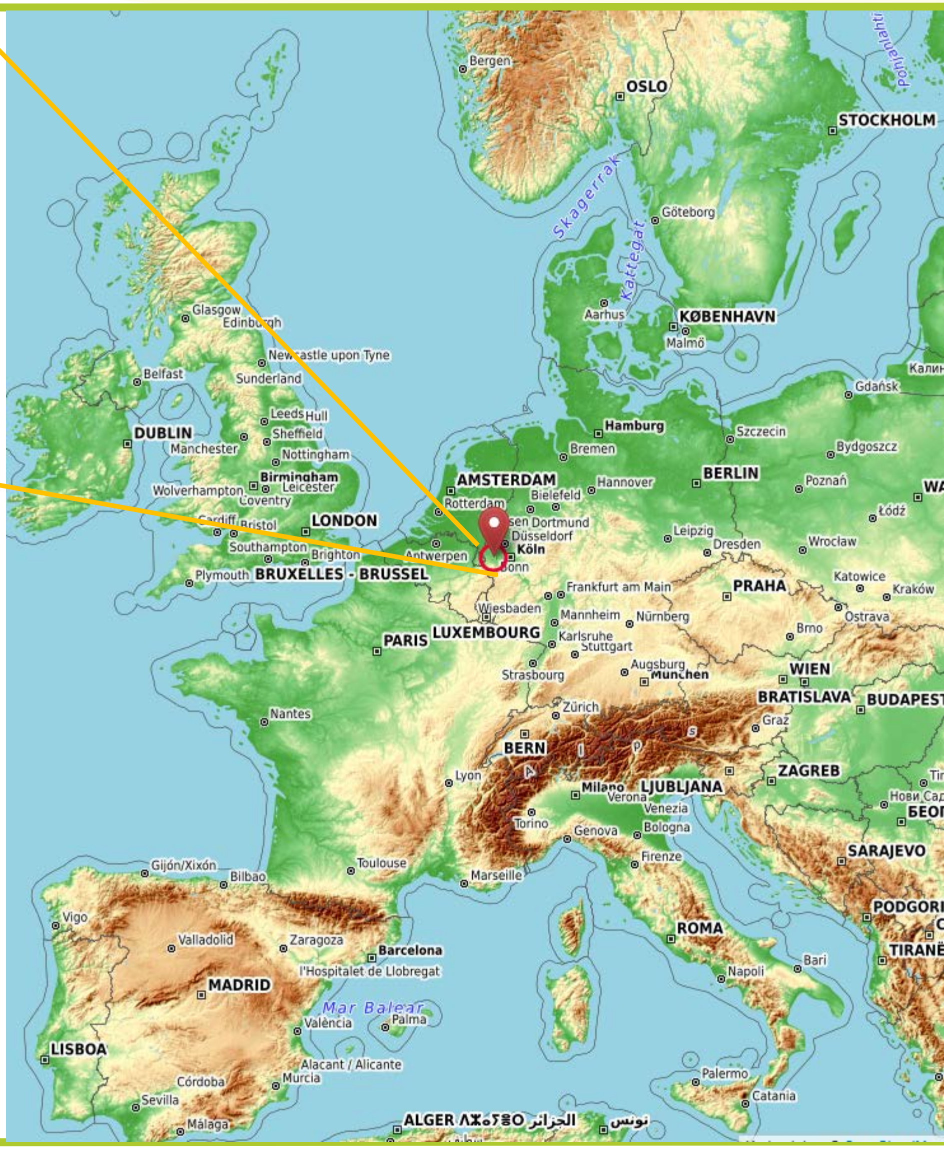


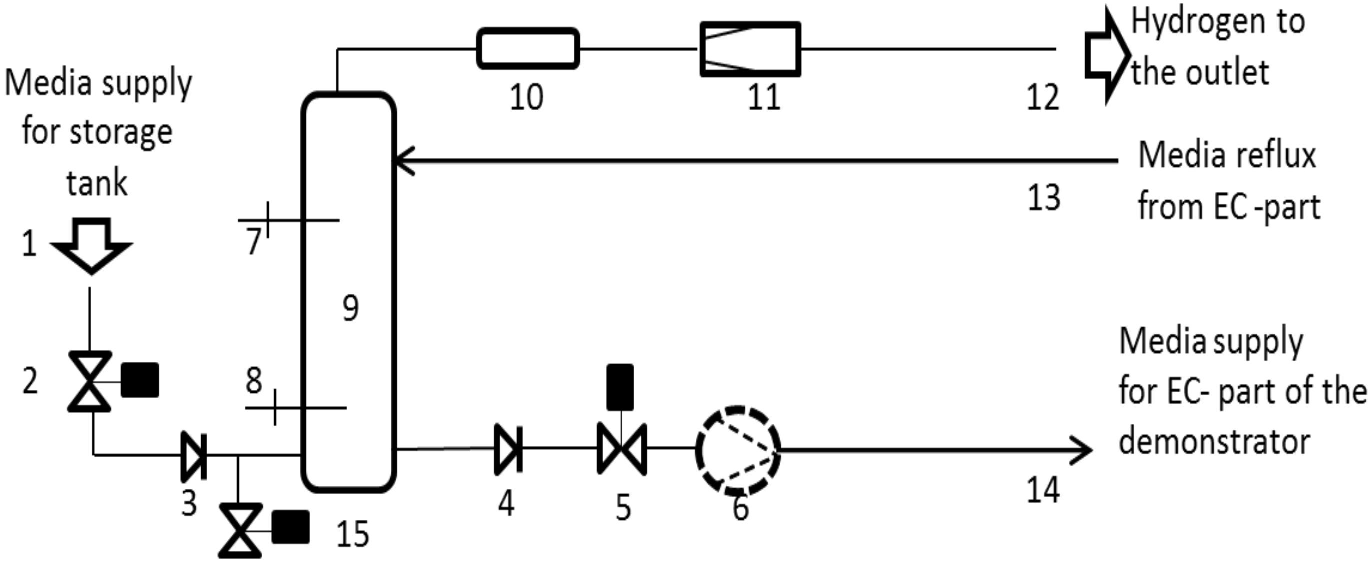
PEM: Polymer Electrolyte Membrane

System location & setup

- Forschungszentrum Jülich GmbH
  50° 55‘ N; 6° 21‘ E
  Height above sea level: 83 m
  Average temperature: 9.8 °C
  Average solar hours: 1528 h
  Rooftop laboratories IEK 14







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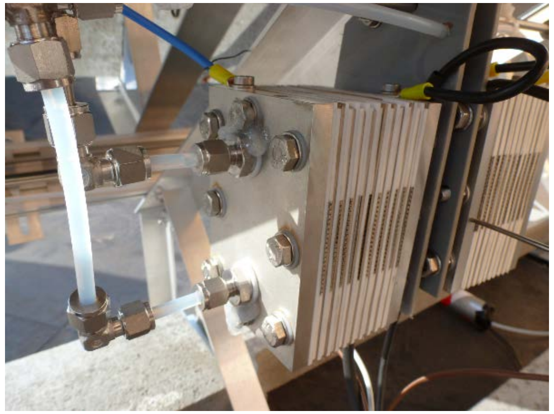

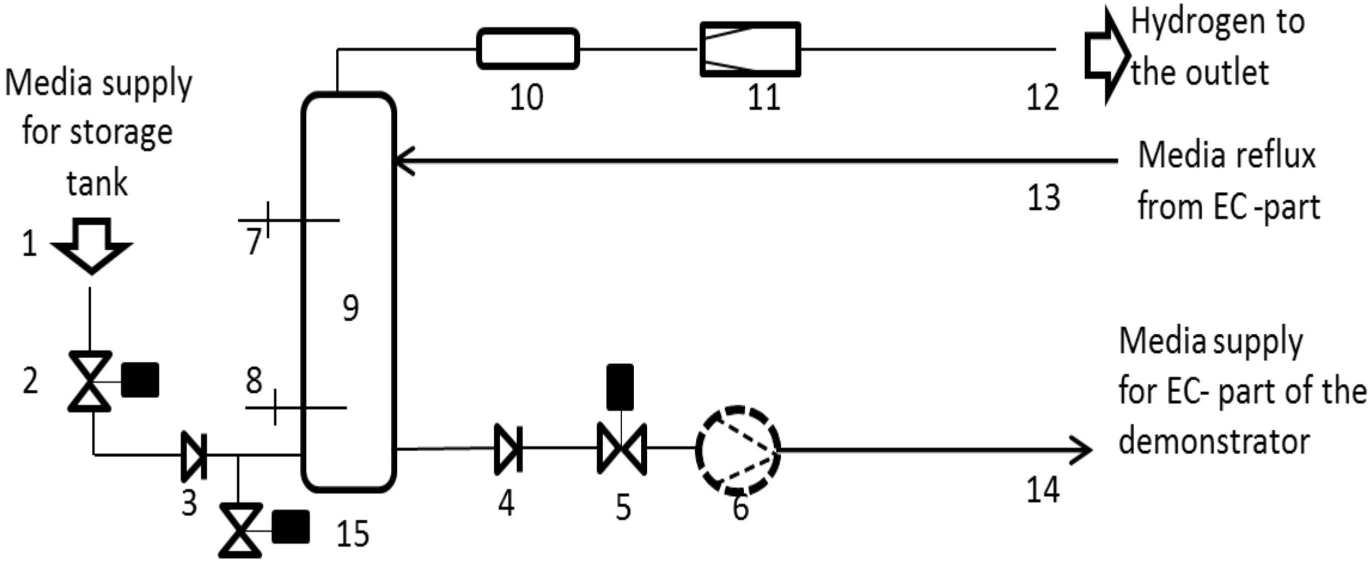

Nr:	Part
1	water supply – demineralized water
2	magnetic valve – water supply
3	non-return valve – water supply
4	non-return valve – water supply
5	magnetic valve
6	circulation pump
7	level sensor
8	level sensor
9	water reservoir / separator
10	drying agent
11	mass flow meter
12	pipe – to storage system
13	Pipe – water / hydrogen
14	Pipe - water
15	magnetic valve

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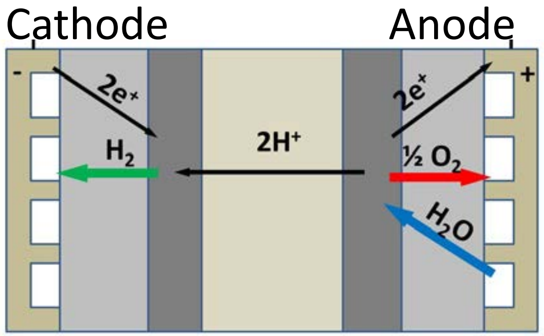
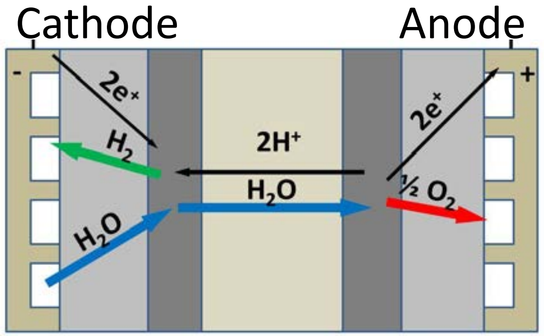
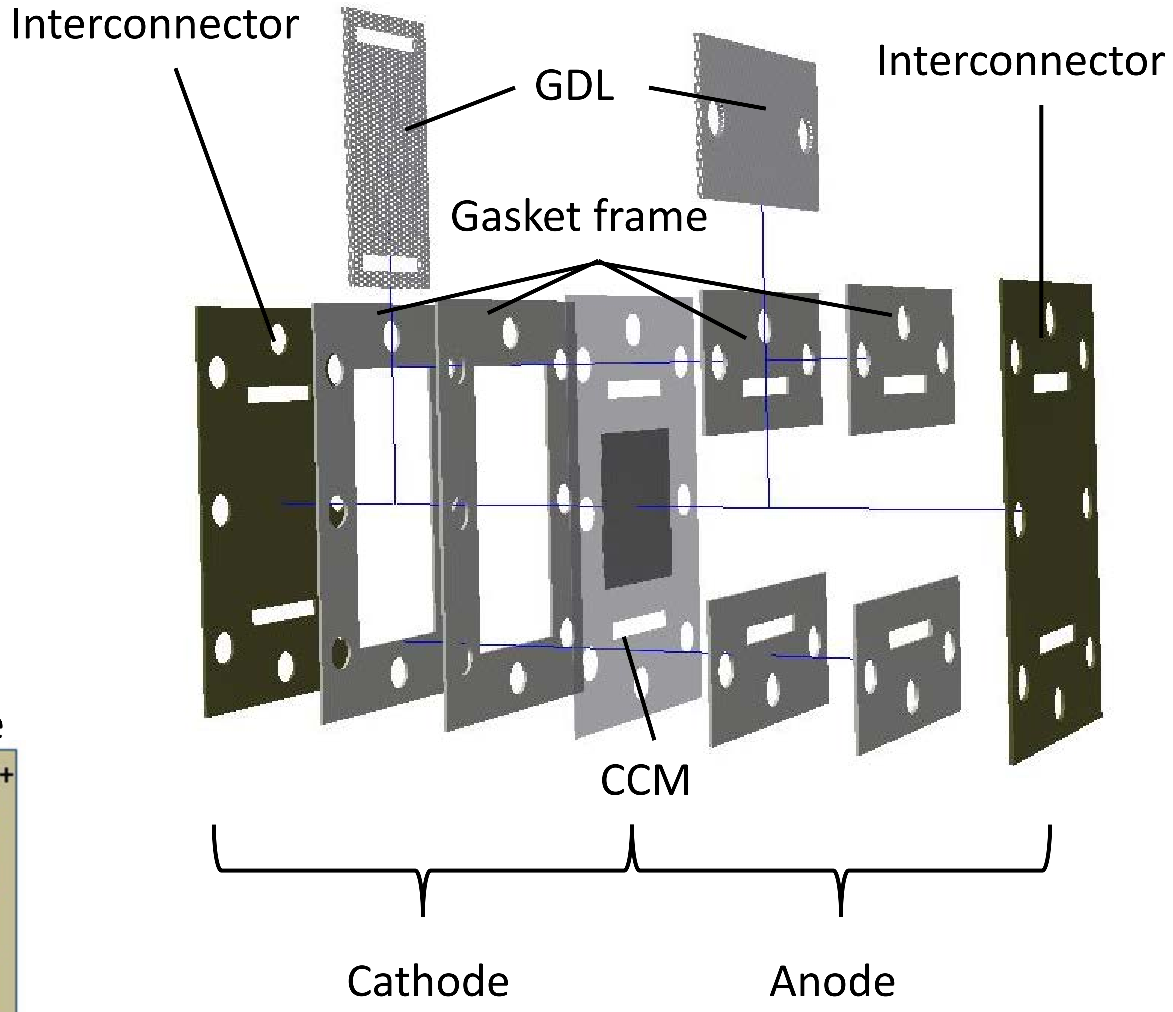
Stack setup "Cassette Design"

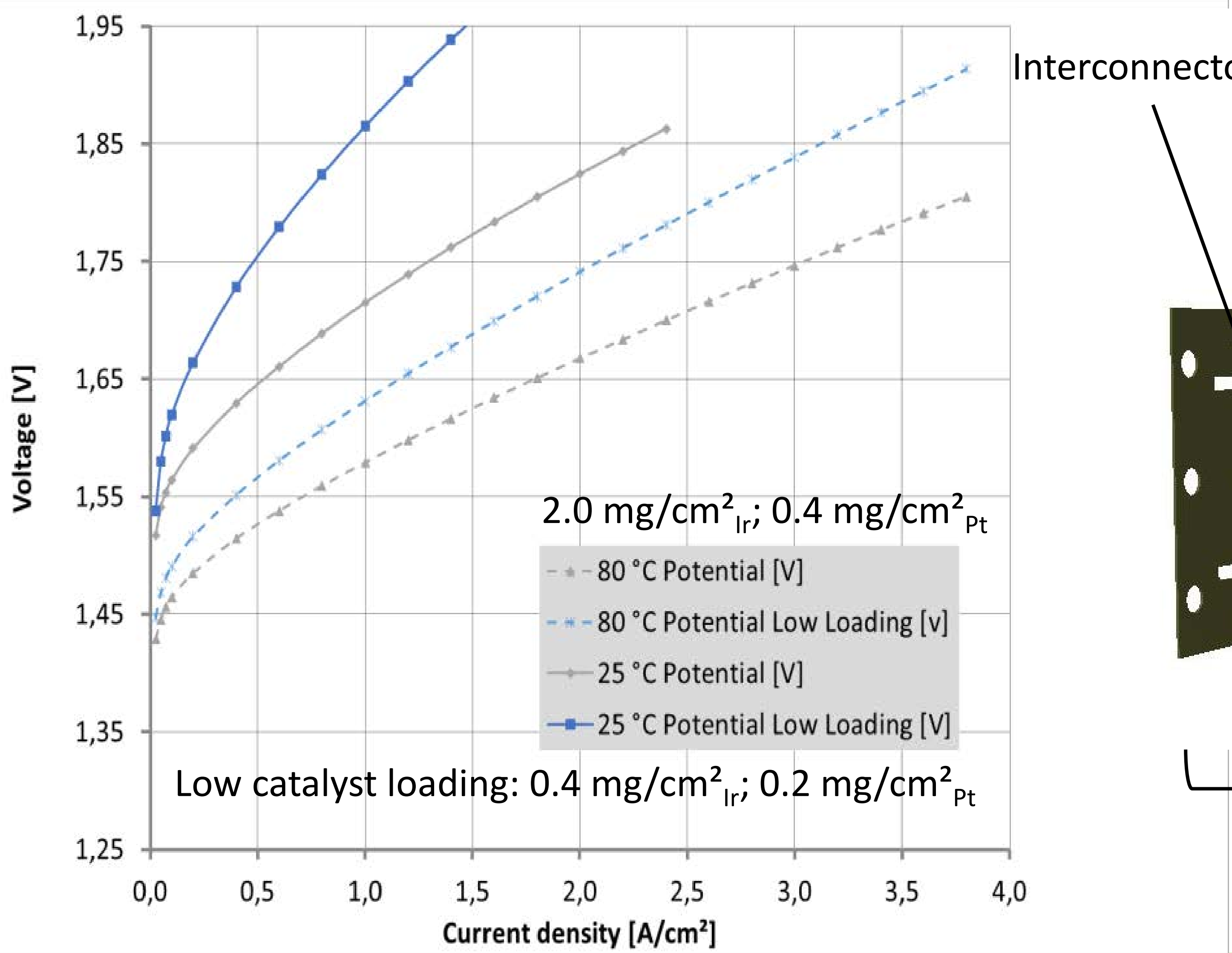
- Expanded mesh for media distribution
  - → No flow field necessary
  - → No pipe necessary for the anode side
- Operation in a pressure range up to 10 bar
  - → H_2 already (pre-) compressed
- No formation of explosive gases
  - → Anode: oxygen dilution in air
  - → Cathode: recombination at platinum catalyst

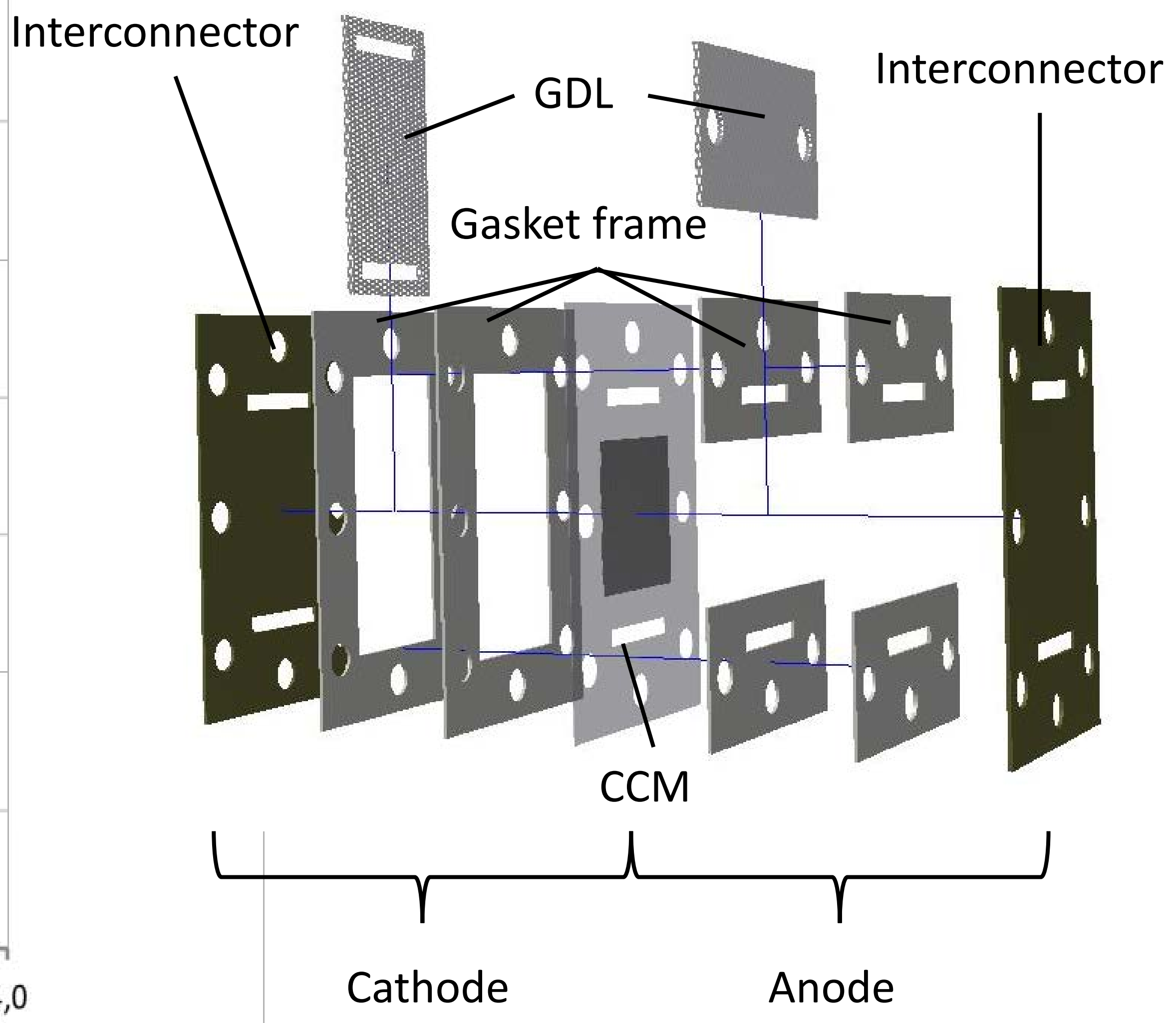






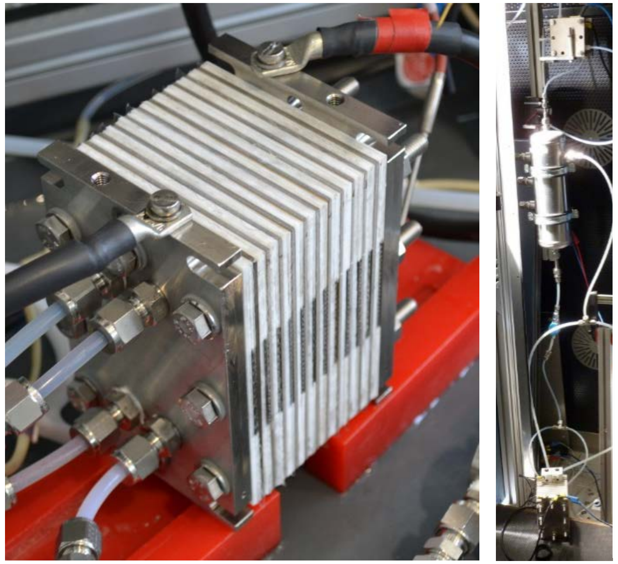
Stack setup "Cassette Design"



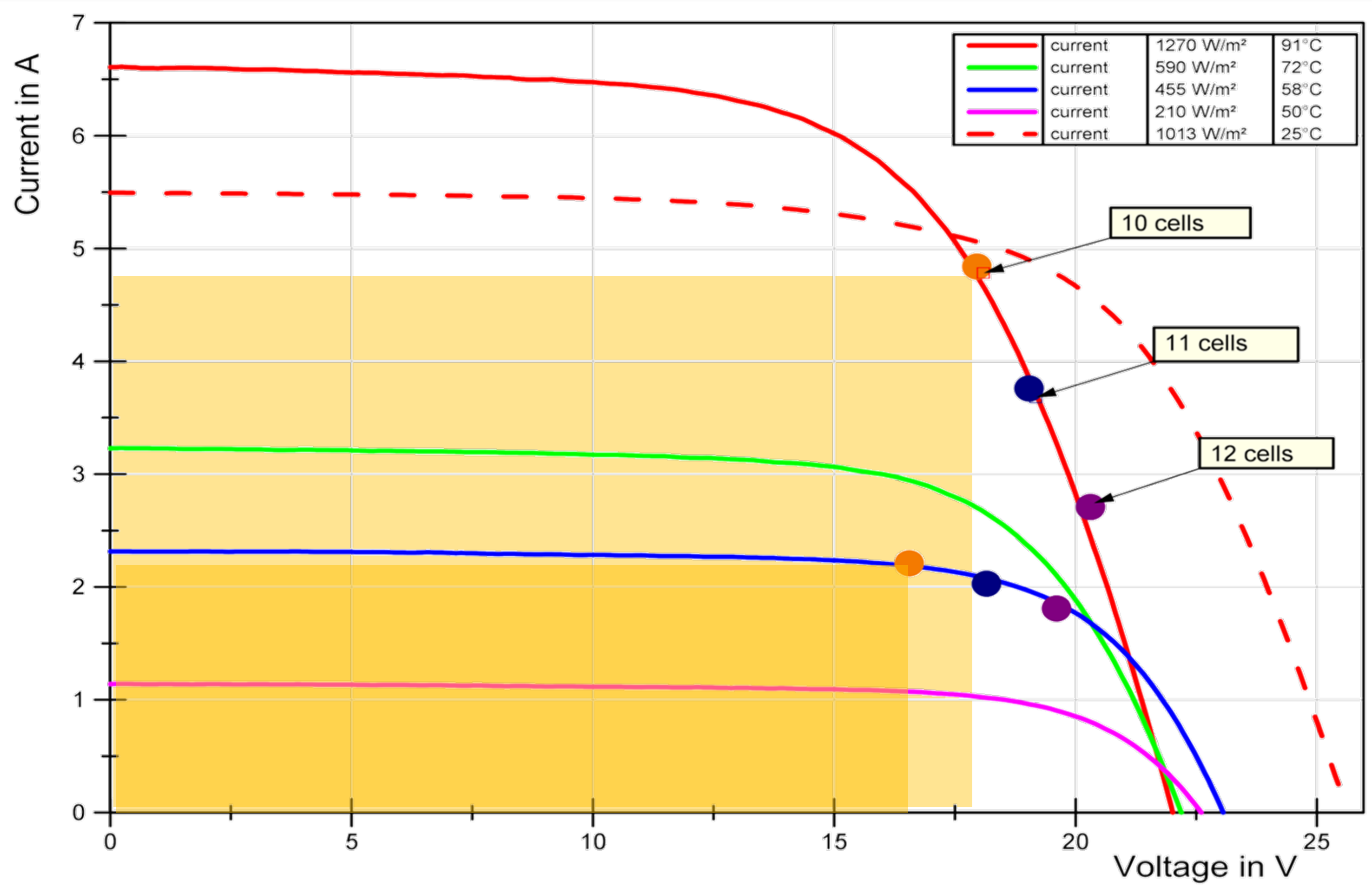


Dimensioning of electrolysis stacks

Sun simulator with PV solibro module (630 x 1190 mm²; 0.75m²)

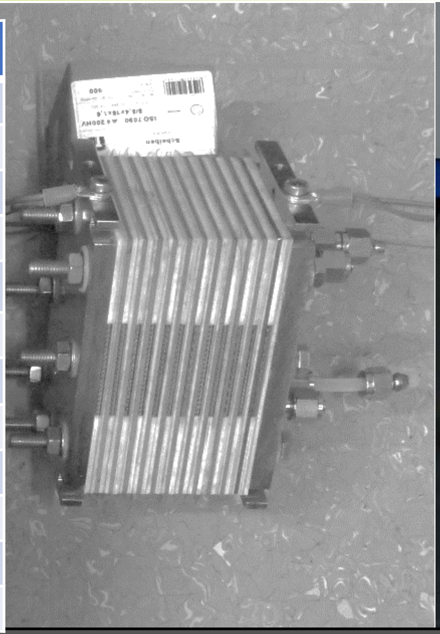


Shift of operating points at different solar radiations and variable EC cell numbers



Prototype of “Cassette Design” Stack

Specific costs of the materials	€/quantity	quantity
Iridium(IV)oxid	79.36	g
Platinum black (HISPEC1000)	76.14	g
Nafion 212	385.25	m^2
PTFE sealant, 2mm	92.67	m^2
Expanded metal (Grade1); 1,7 mm	2406.25	m^2
TORAY Paper	301.81	m^2
Bipolar plate metal sheet 1 mm titanium	174	m^2
End plate 1.4571	314	m^2
Screw-in adapter 1/4" X 6 mm	5	St
Threaded rod M8, 1000mm	1	St
Nuts	0.05	St
Washers	0.01	St



Type of PEM electrolyser	PV configuration	Replications
Low catalyst loading 0.4 mg/cm^2_{Ir}; 0.2 mg/cm^2_{Pt}	One module Enel HJT	1
	One module Solibro CIGS	3
Standard catalyst loading 2.0 mg/cm^2_{Ir}; 0.4 mg/cm^2_{Pt}	One module Enel HJT	1
	One module Solibro CIGS	1
	Two modules, in parallel, Solibro CIGS	1

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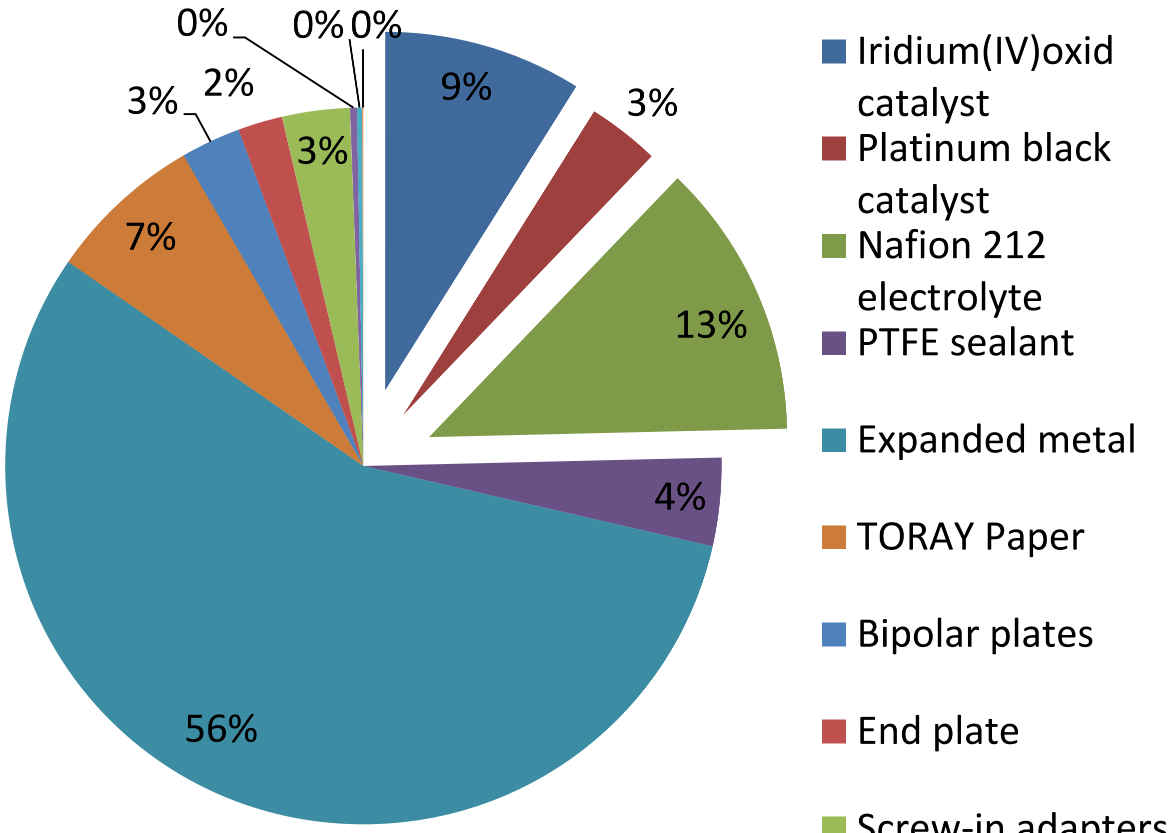
Calculation of material costs of the cassette design



Material costs of the different cassettes

Component	10 cell stack high catalyst loading	10 cell stack low catalyst loading	20 cell stack high catalyst loading	20 cell stack low catalyst loading
Iridium(IV)oxid catalyst	29.36	5.32	58.73	10.63
Platinum black catalyst	10.66	1.75	21.32	3.50
Nafion 212 electrolyte	40.93	40.93	81.87	81.87
PTFE sealant	13.00	13.00	25.99	25.99
Expanded metal	184.08	184.08	368.16	368.16
TORAY Paper	23.09	23.09	46.18	46.18
Bipolar plates	8.81	8.81	18.60	18.60
End plate	6.67	6.67	6.67	6.67
Screw-in adapters	10	10	10	10
Threaded rod	1	1	2	2
Nuts	0.8	0.8	0.8	0.8
Washers	0.16	0.16	0.16	0.16
SUM	**329**	**296**	**640**	**575**

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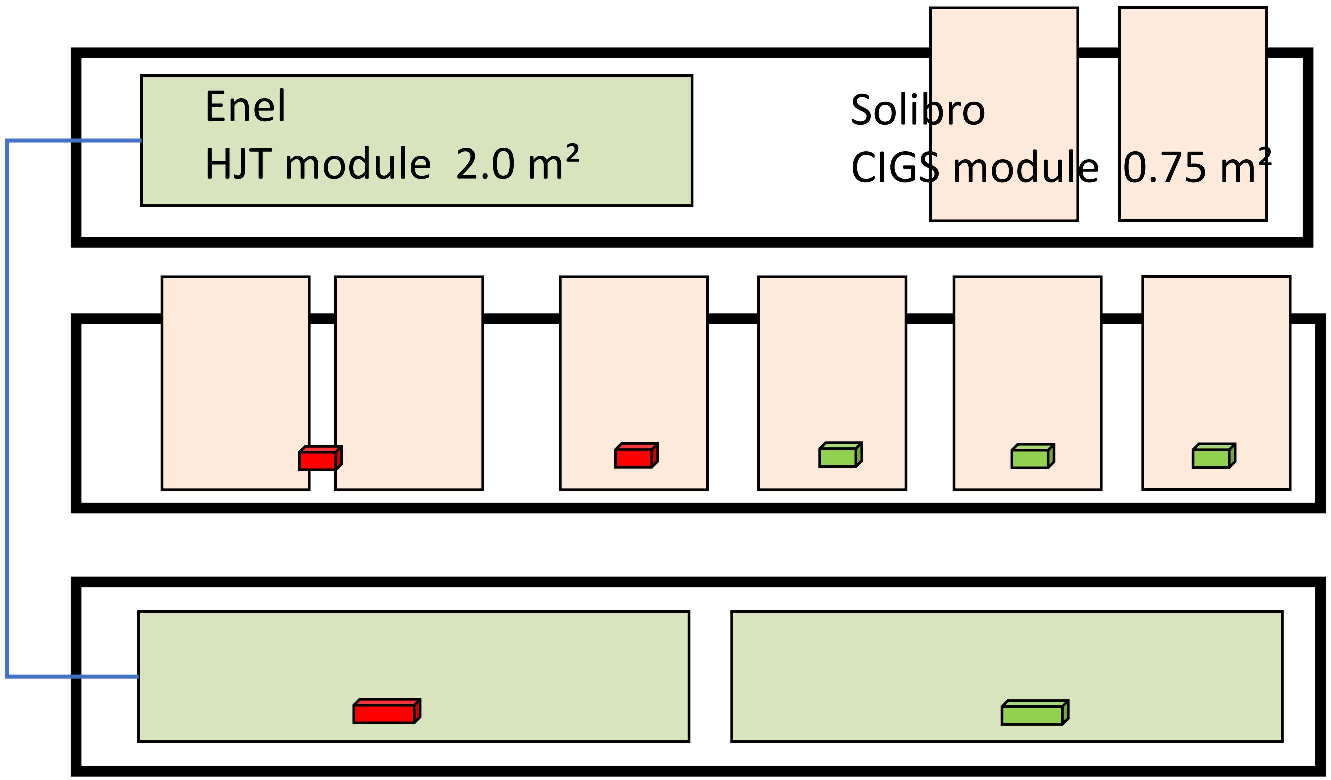
Arrangement of PV / EC combinations on the test field

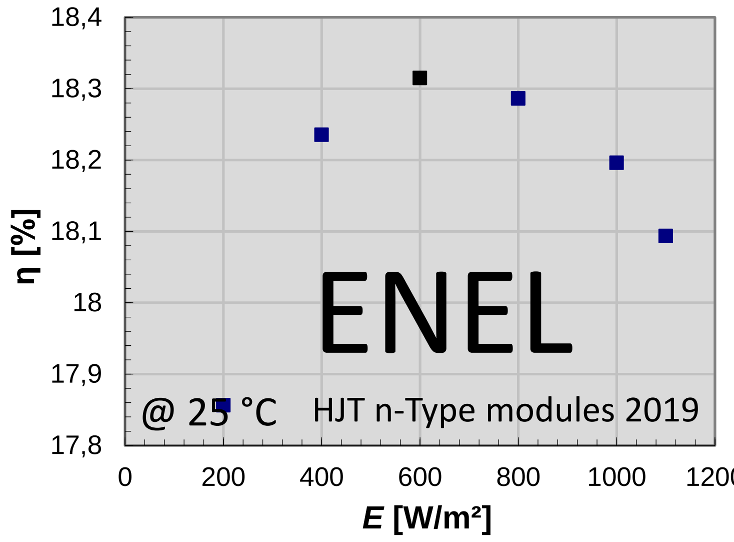


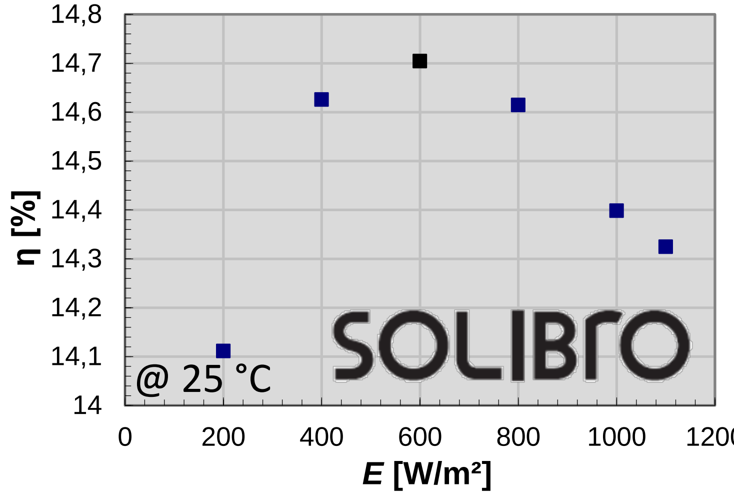
Casette low loadinig   Casette standard loadinig

Framework
3 rows;
4 m length

Solibro
CIGS modules
4.5 m²
η_{PV} : 12-15 %

Enel
HJT modules
4.0 m²
η_{PV} : 18-20 %





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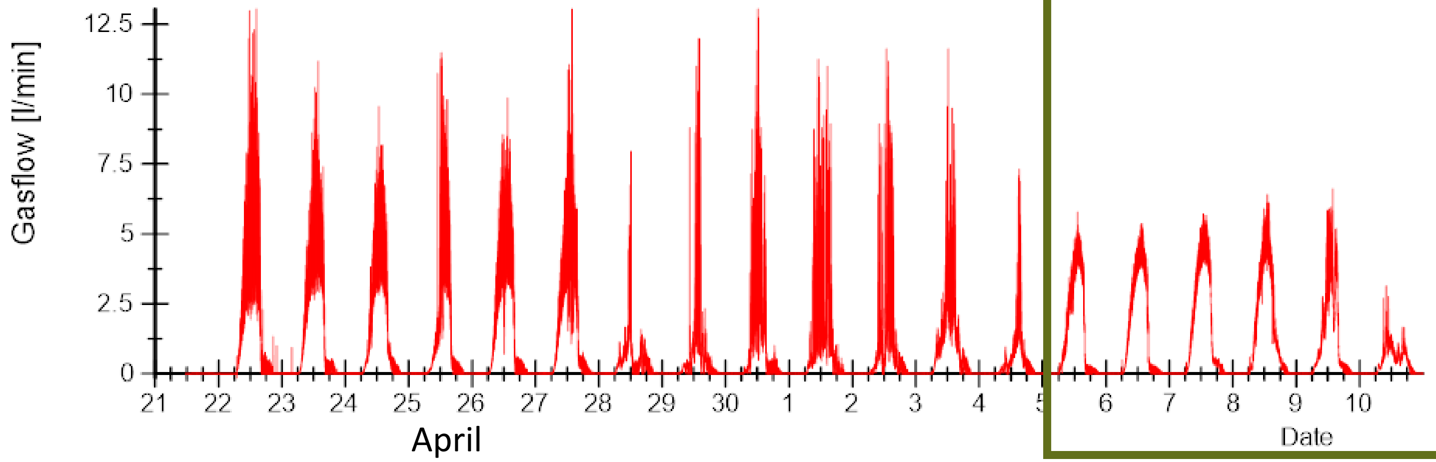
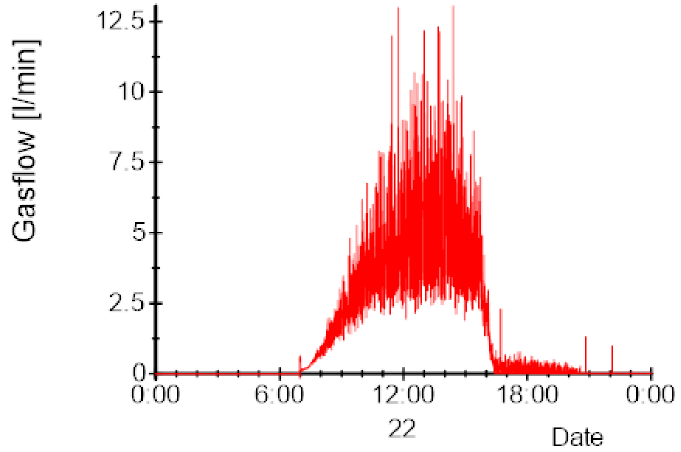
Arrangement of PV / EC combinations on the test field

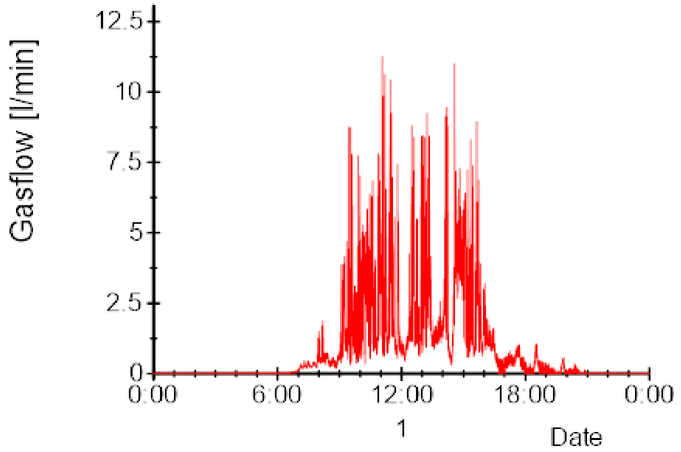
Detection of gas flow during operation

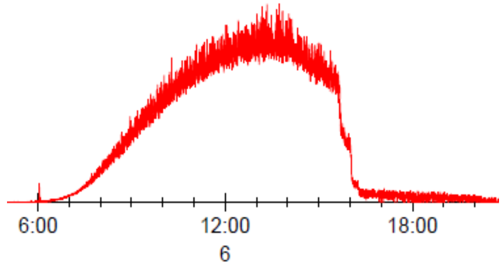


Improved setup: slightly pressurized gas evolution

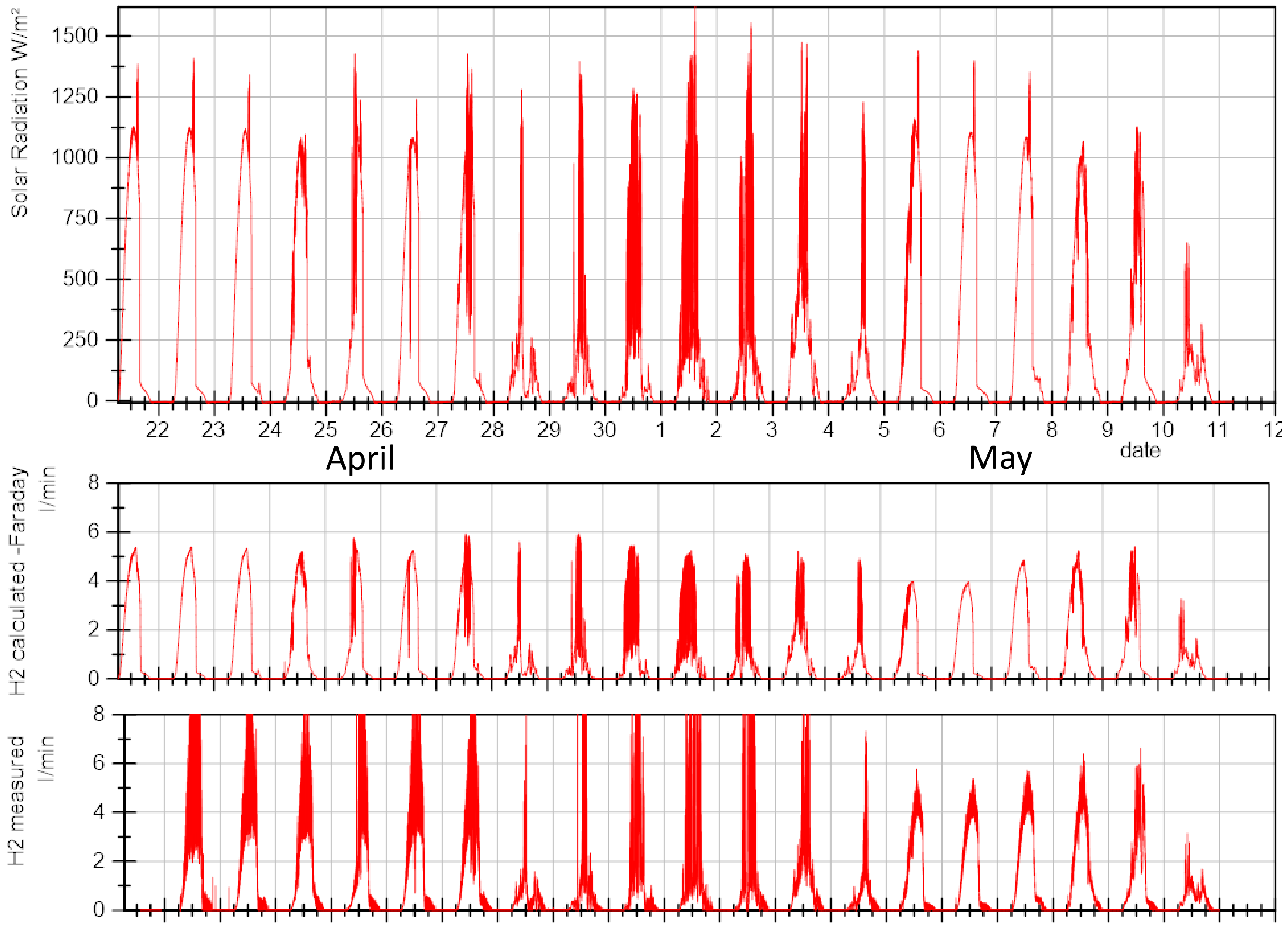
Hydrogen generation; sunny day (left) cloudy day (middle) improvement of measured signal (right)







Measured solar radiation and hydrogen flow



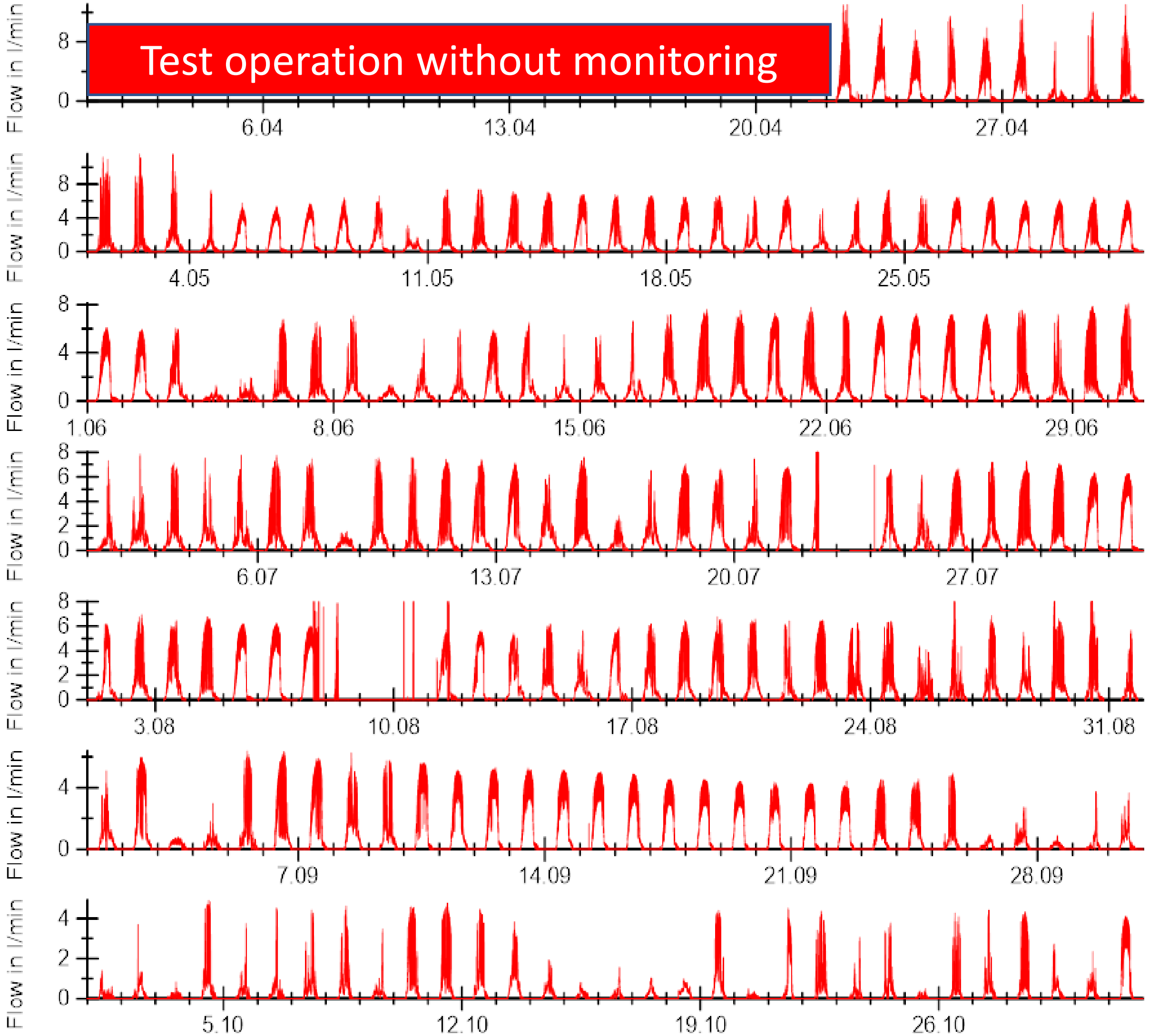
Measured solar radiation

Hydrogen flow calculated by Faradaic law

Hydrogen flow measured

Good correlation

Timeline of hydrogen generation in the plant



April

May

June

July

August

September

October

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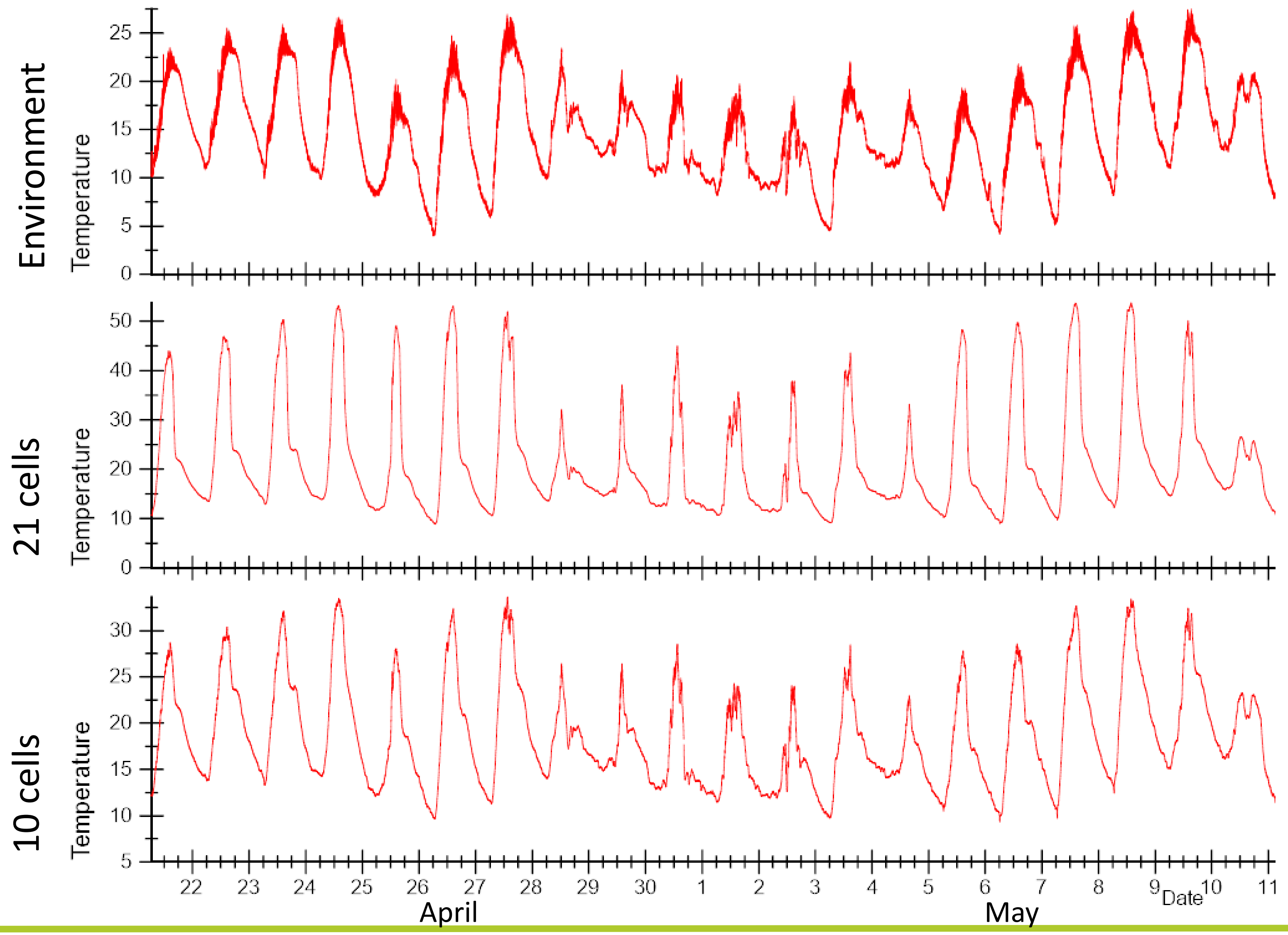
Temperature during operation

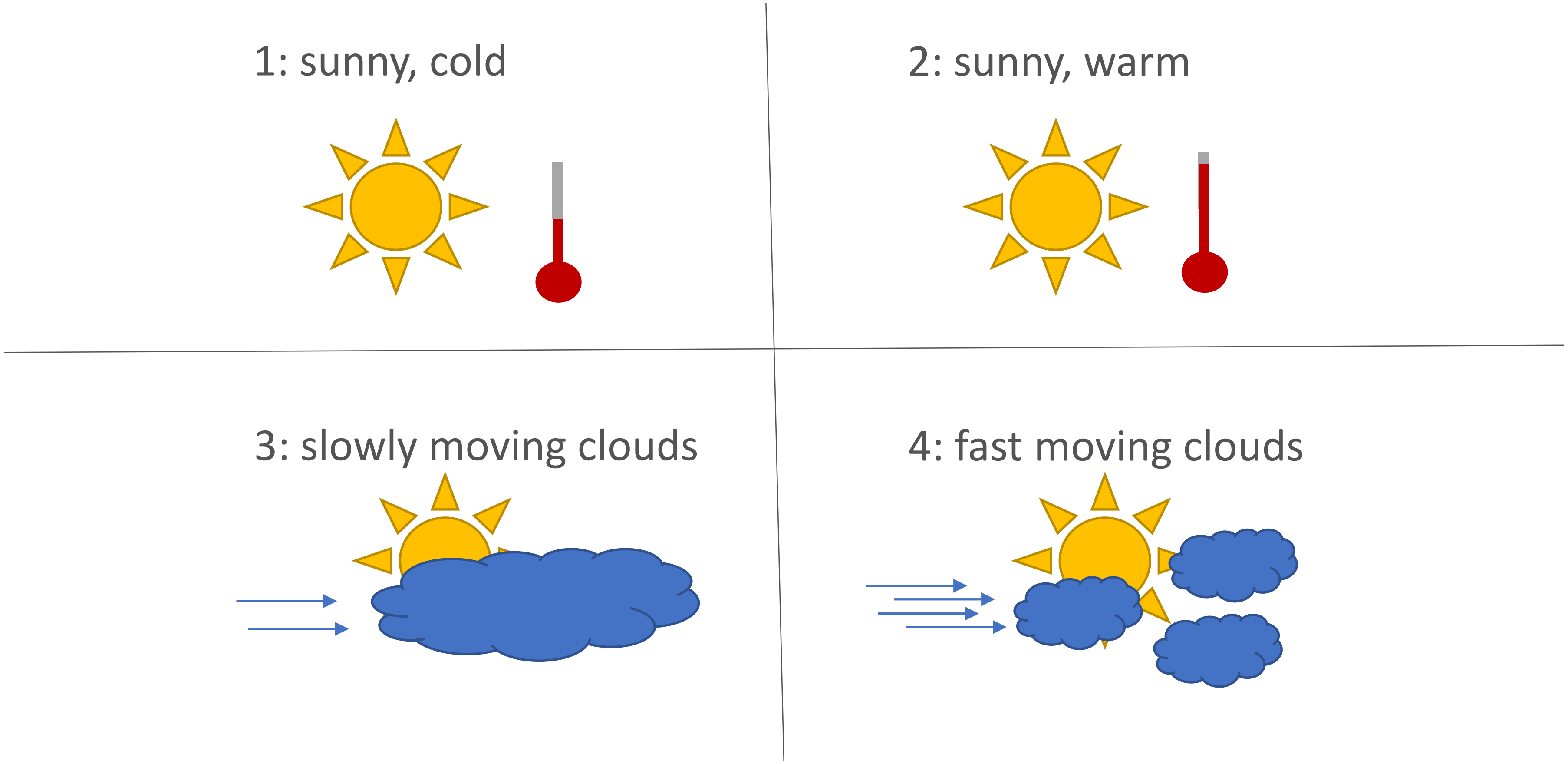


Large stacks (higher active area in relation to stack surface) reach higher operating temperatures what leads to a improved performance (efficiency)

T_{max}: >50 °C

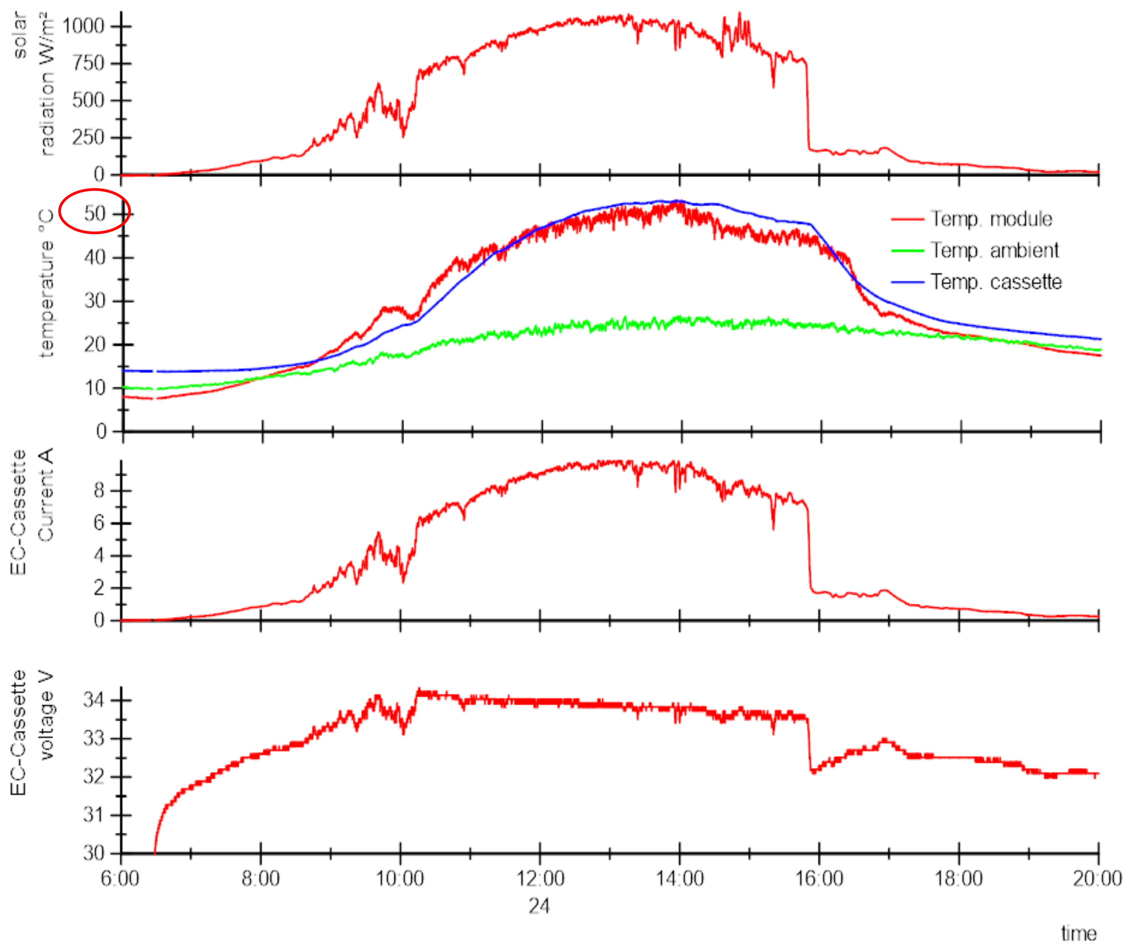
T_{max}: ~35 °C

Different characteristic of H_2 generation pattern

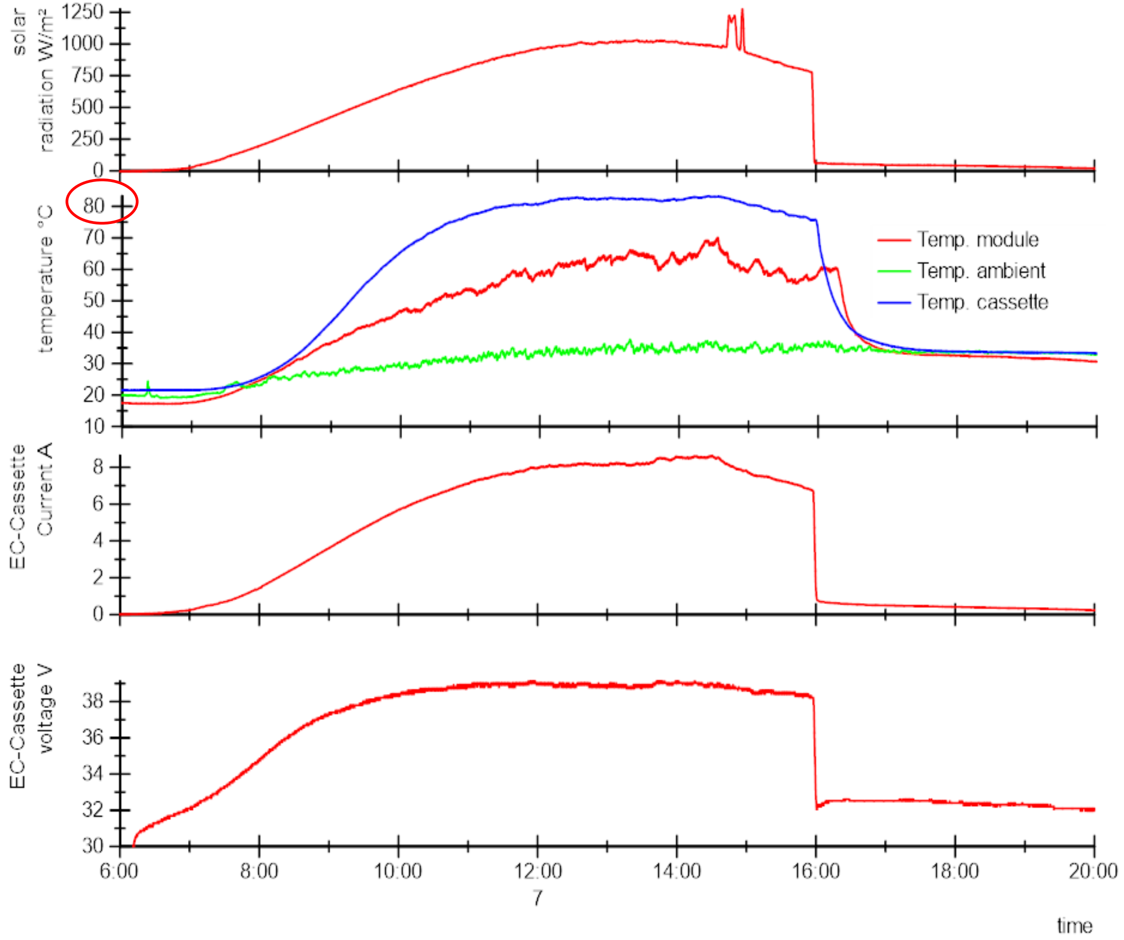


Different characteristic H2 generation pattern

1: sunny; cold



2: sunny; warm



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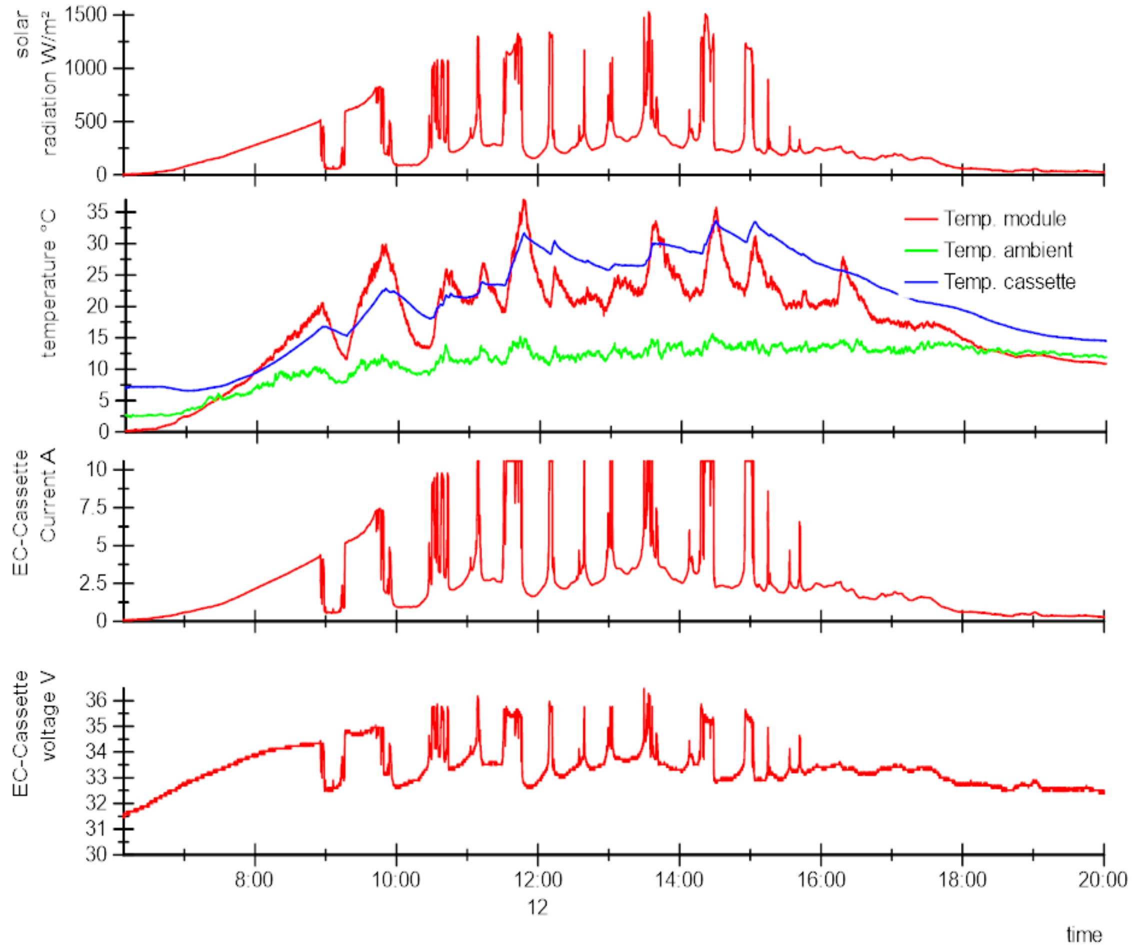
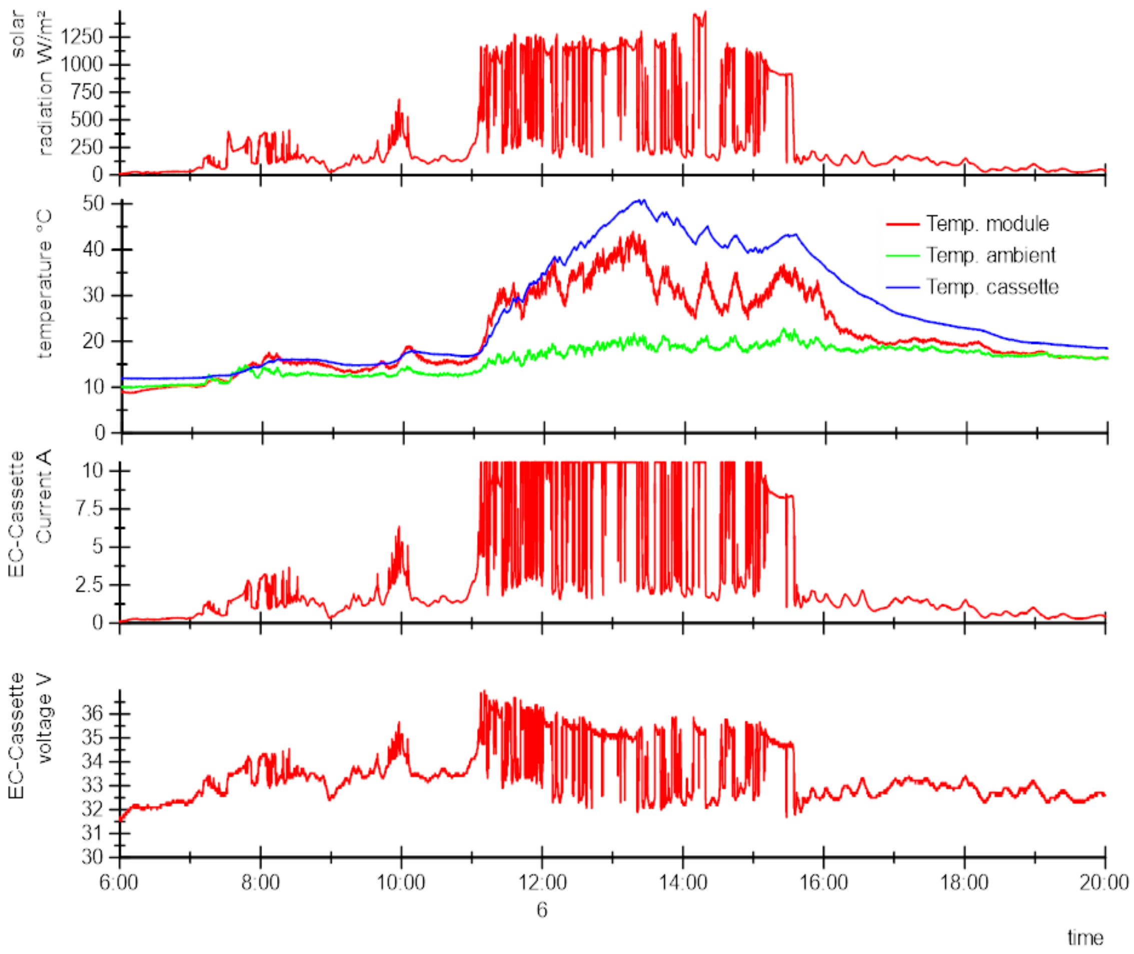
Different characteristic H2 generation pattern

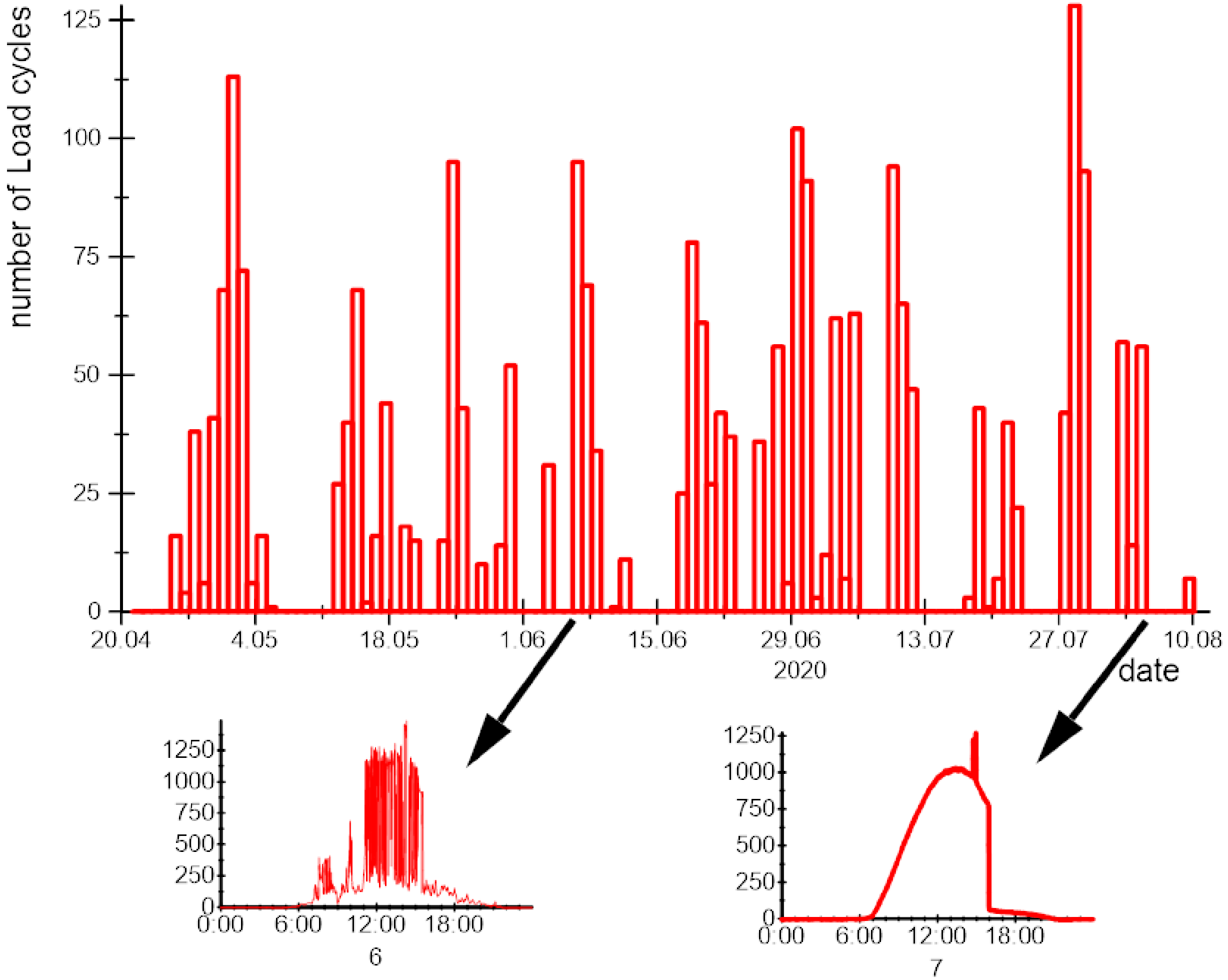
3: slowly moving clouds

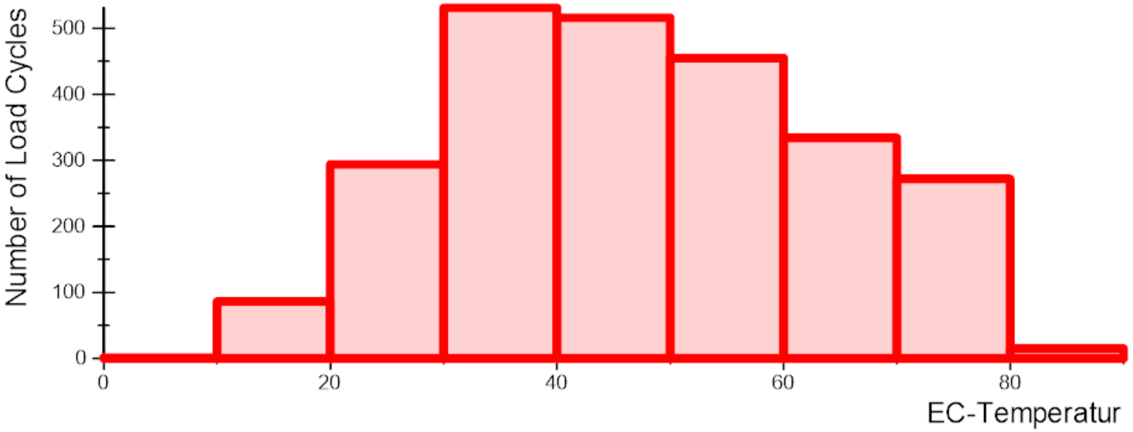


4: fast moving clouds



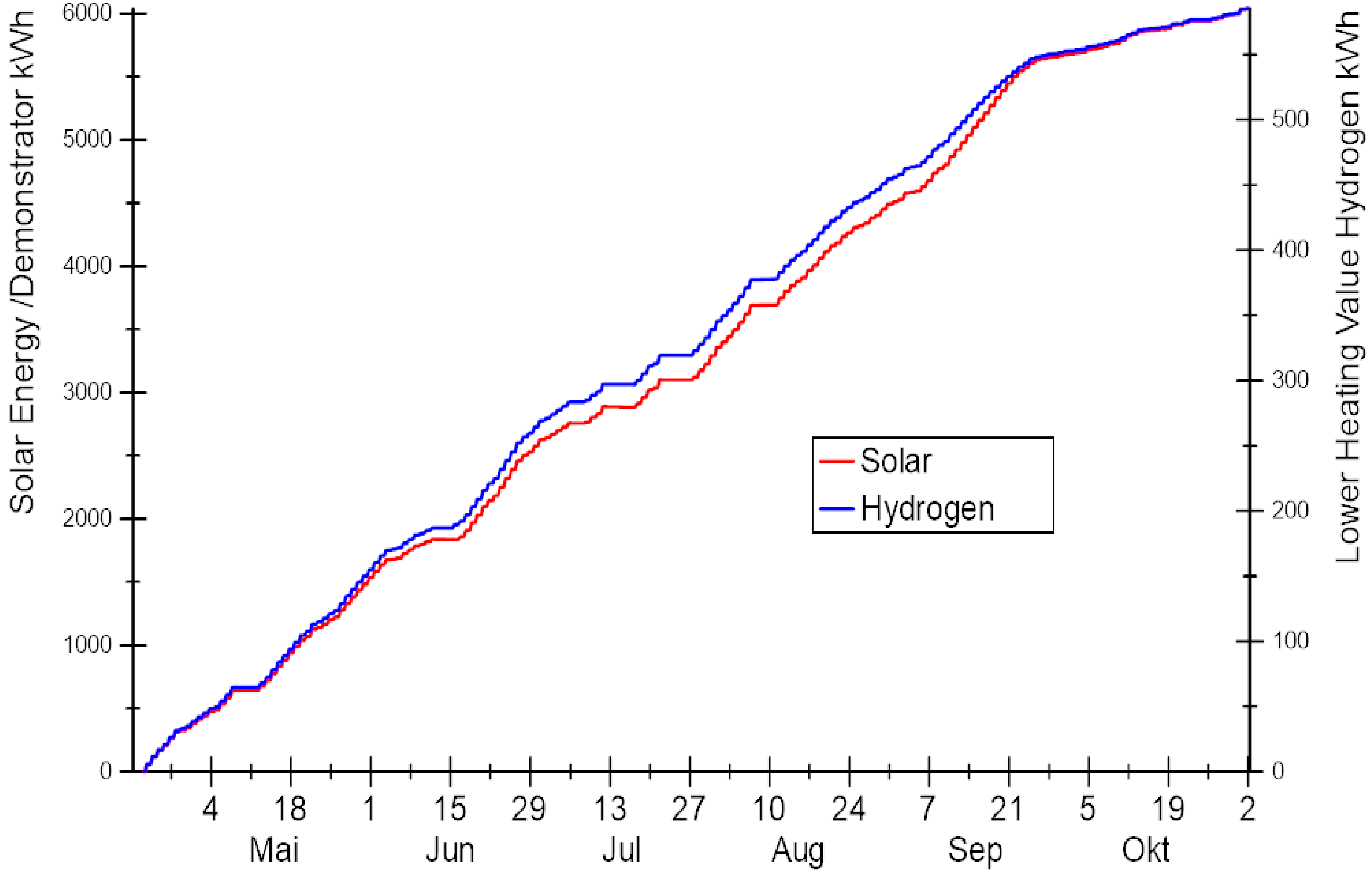
Load cycles during operation





number of Load cycles	Temperature
1	5
86	15
294	25
531	35
516	45
455	55
334	65
272	75
15	85

Hydrogen generation in 10 m² demonstrator



Datum	StH / Faraday	StH / Gas measurement
23 Apr.	10.9	9.9
24 Apr.	11.4	10.3
25 Apr.	11.4	10.2
26 Apr.	11.1	9.9
27 Apr.	10.9	10
28 Apr.	11.7	10
29 Apr.	11.5	10.1
30 Apr	10.9	9.7
01 Mai	10.7	9.8
02 Mai	11.0	10.2
03 Mai	11.3	10
04 Mai	12.5	10.7
05 Mai	11.2	10.2
06 Mai	11.0	10.0
07 Mai	11.1	10.0
08 Mai	10.5	9.9
09 Mai	11.4	10.8
10 Mai	11.6	10.8

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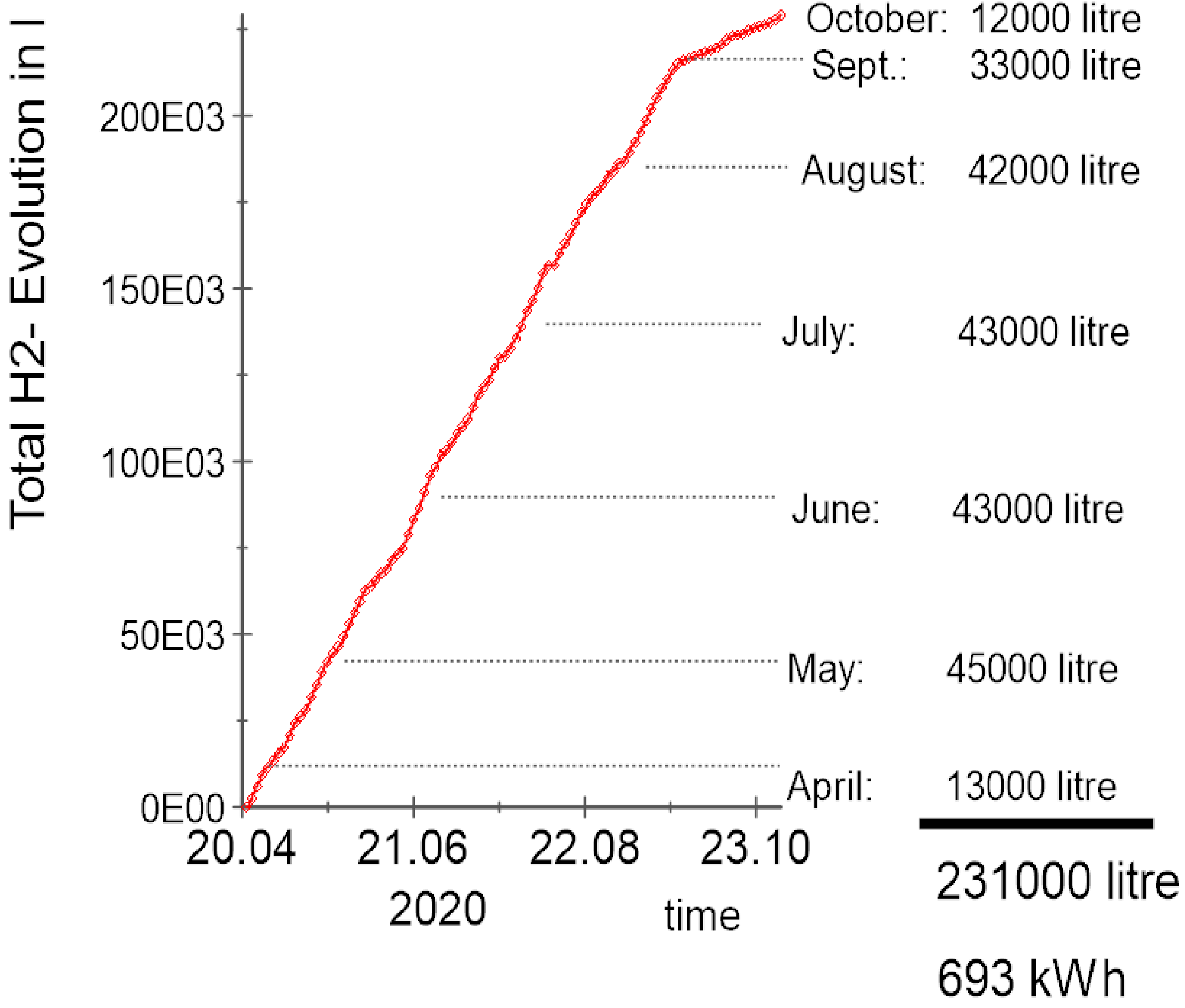
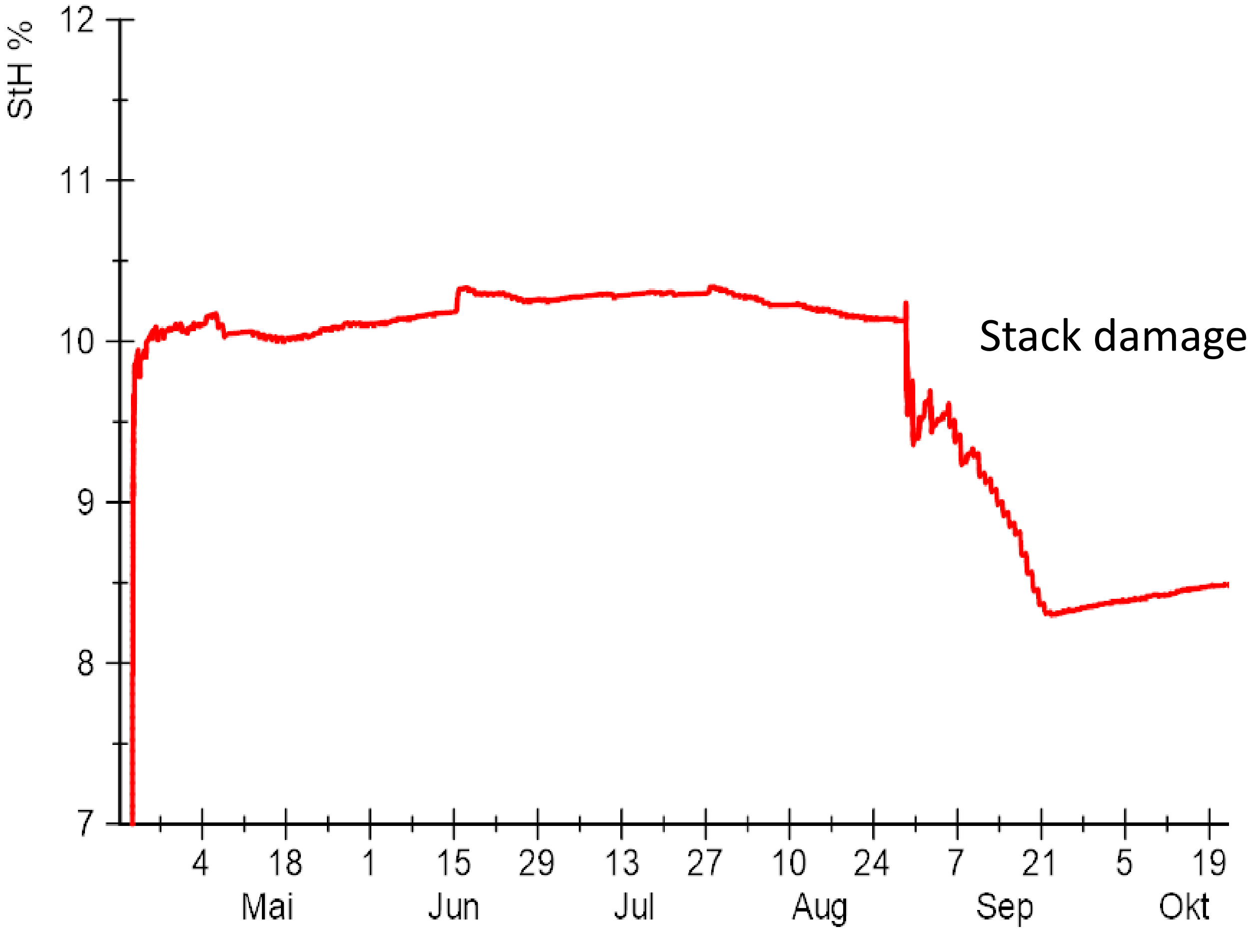
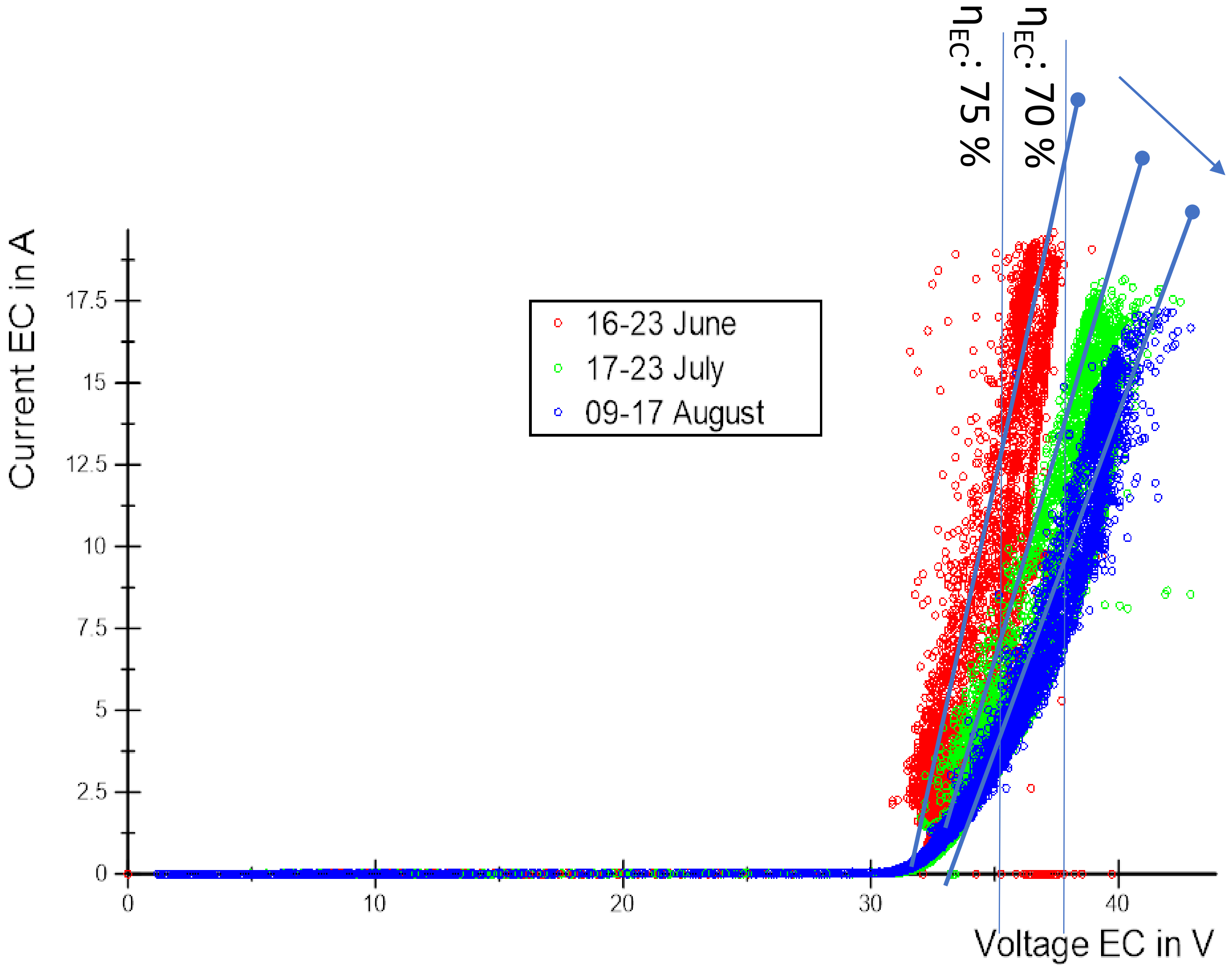
Hydrogen generation in 10 m² demonstrator





Degradation of electrolysis stack with low loading

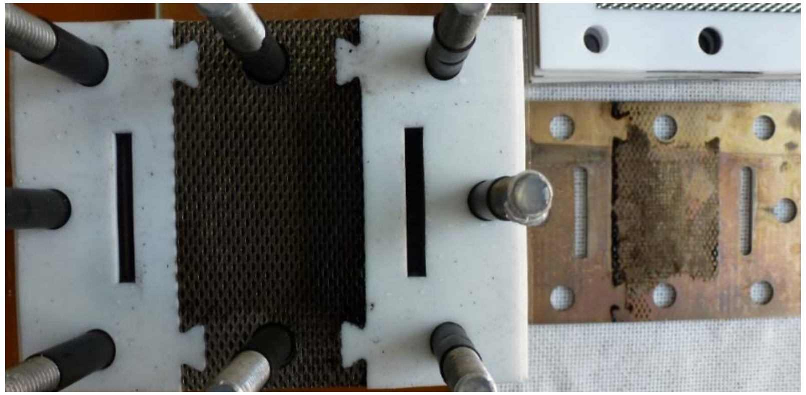


Increase of Ohmic losses

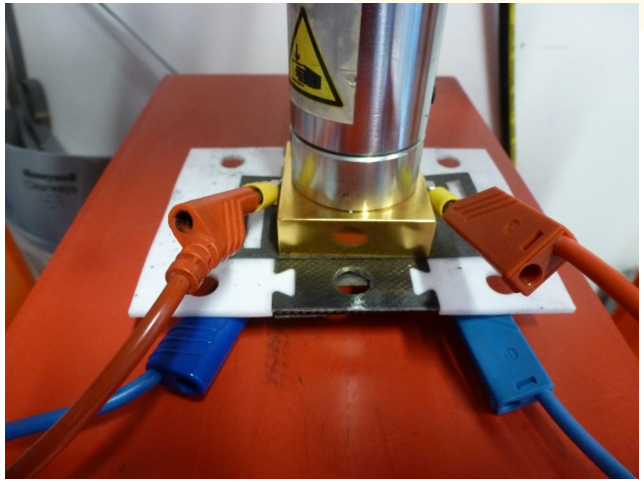
- Corrosion of electrodes
- Corrosion of catalysts
- Impurities

Analysis of cell & stack defects

Diffusion layer; anode side CCM



Flow distribution and BPP; anode side



→ Damage of diffusion layer (carbon coated Paper)

→ Corrosion at surfaces

Increase of contact resistance by a factor of 3 (from 7.5 mΩ to 24 mΩ).

Further analysis is necessary and will be carried out.

Conclusions and Outlook

- Direct coupling is reliable and cost effective
- Efficiency is all over the year in the range of 10 %
- Durability of more than 6 month (~2,500 h) was demonstrated
- Generation of 231,000 liters Hydrogen

- Degradation of electrolysis components
  - Electrical contact resistance
  - Corrosion and contaminations
  - …

Further analysis is necessary

- Further research in terms of systems reliability is necessary
- Further research for scaling up alkaline electrolysis is necessary

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Progress beyond state of the art and impact

- Progress beyond state of the art
  - New stack and system concept was developed and its function was proven in dynamic operation

- Impact
  - Possible weaknesses of the technology could be identified and this information serves as a basis for the further development and identification of future research questions

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Thank you for your attention!

Acknowledgements

- Solibro and ENEL for the provision of the PV panels
- FZJ central workshop for manufacturing the components
- All colleagues that make it possible
- The EU for funding the project

Questions

Publications and conference presentations

- Martin Müller*,Walter Zwaygardt, Edward Rauls, Michael Hehemann, Stefan Haas , Lars Stolt, Holger Janssen and Marcelo Carmo (2019): Characteristics of a New Polymer Electrolyte Electrolysis Technique with Only Cathodic Media Supply Coupled to a Photovoltaic Panel, Energies, 12 (21), 4150.

- Please take a look al the PECSYS web page for additional publications.

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