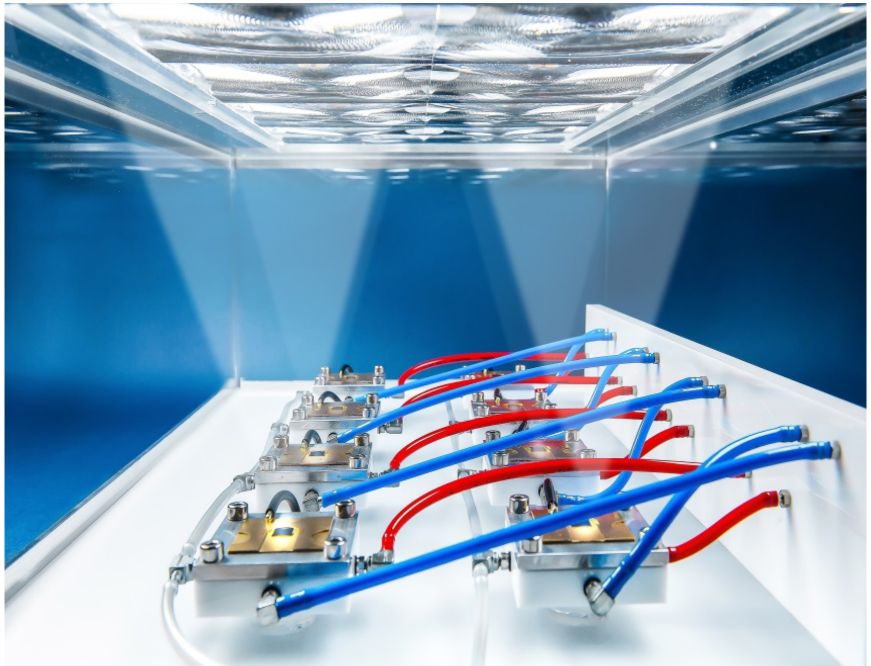
Highly Efficient Solar Hydrogen Generation – An Integrated Concept with III-V Solar Cells and PEM Electrolysis Cells



Arne Fallisch, Paul Förster, Jens Ohlmann, Tom Smolinka and Mario Zedda

Fraunhofer Institute for Solar Energy Systems ISE

IMPRES 2016
Taormina - Italy, October 25, 2016
www.ise.fraunhofer.de

Fraunhofer ISE

Fraunhofer Institute for Solar Energy Systems ISE
At a Glance

Fraunhofer ISE

Director: Prof. Eicke R. Weber

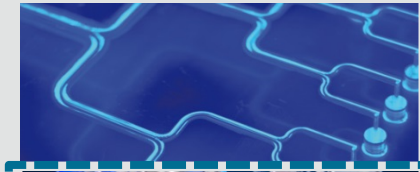
Staff: ca. 1100

Budget 2015: 84 Mio. EUR

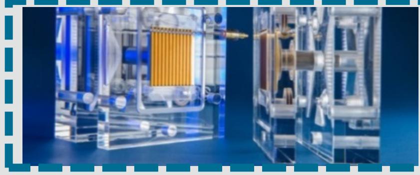
Established: 1981

Photovoltaics

Solar Thermal Technology



Building Energy Technology



Hydrogen Technology

Energy System Technology

Fraunhofer ISE

Overview

- Introduction to the **Hy**drogen **Con**centrator
- PEM water electrolysis cells
  - Cell design
  - Performance
- HyCon demonstrator
  - System layout
  - Outdoor measurements
- Summary

Introduction to the Hydrogen Concentrator
The need of hydrogen as secondary energy carrier

- Energy sources by fluctuating renewables like wind and solar
- Batteries enable short and mid-term storage
- Hydrogen (and other chemical energy carriers) enables long-term storage
- Hydrogen can be used in different applications as energy carrier
  - Transport sector
  - Power market
  - Residential applications
  - Chemical industry

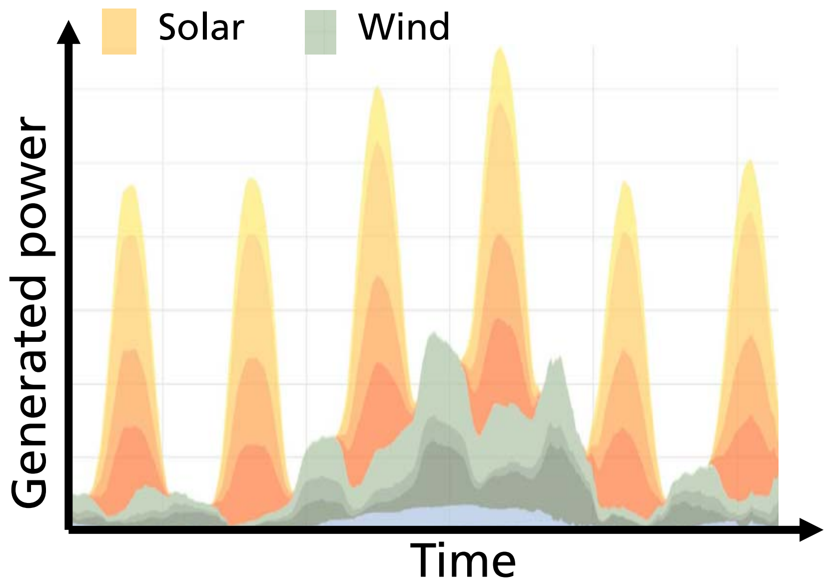


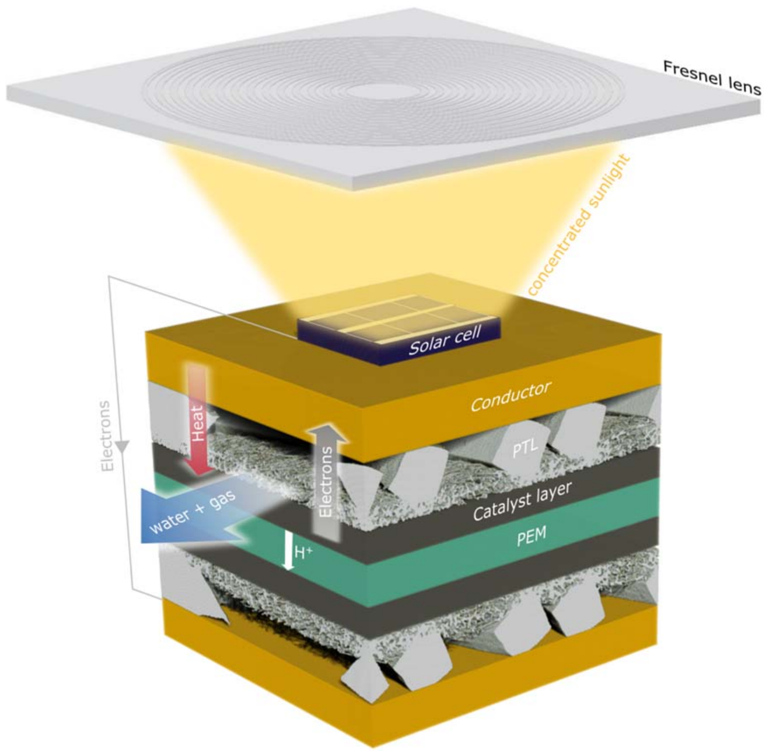
Fig. 1: Fluctuating solar & wind power

www.energy-charts.de/power_de.htm

Fraunhofer ISE

Introduction to the Hydrogen Concentrator
Main principle

- Direct coupling of III-V multi-junction solar cells with PEM water electrolysis cells
- High efficiency due to very low losses (up to now $\varepsilon_{\mathrm{HyCon}} \sim 18\ \%$)
- No additional power electronics required
- Natural convection is possible
- Enhanced thermal management in a 1:1 interconnection
- No switching between H_2 and current possible

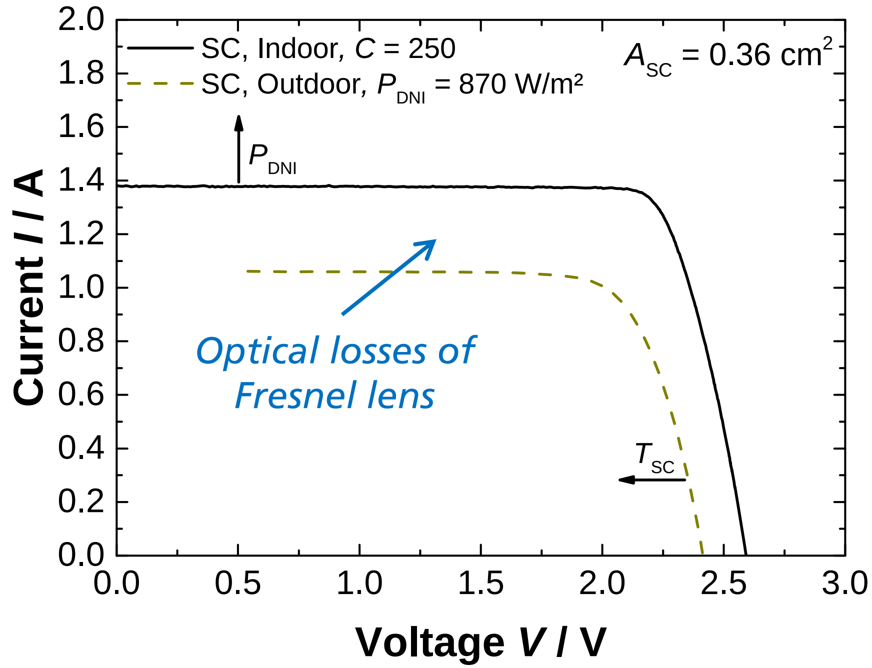


Schematic view of a HyCon module

F. Dimroth, Patent DE 102004050638 B3, 2004
F. Dimroth, G. Peharz, U. Wittstadt and A. W. Bett, Photovoltaic Energy Conversion, 2006

Introduction to the Hydrogen Concentrator
Operation point of a HyCon module

- Higher irradiance P_{DNI} generates higher current
- Higher temperature T_{SC} decreases voltage of solar cell
- Difference between indoor and outdoor measurement mainly due to optical losses of the Fresnel lens



IV curves of a triple-junction solar cell

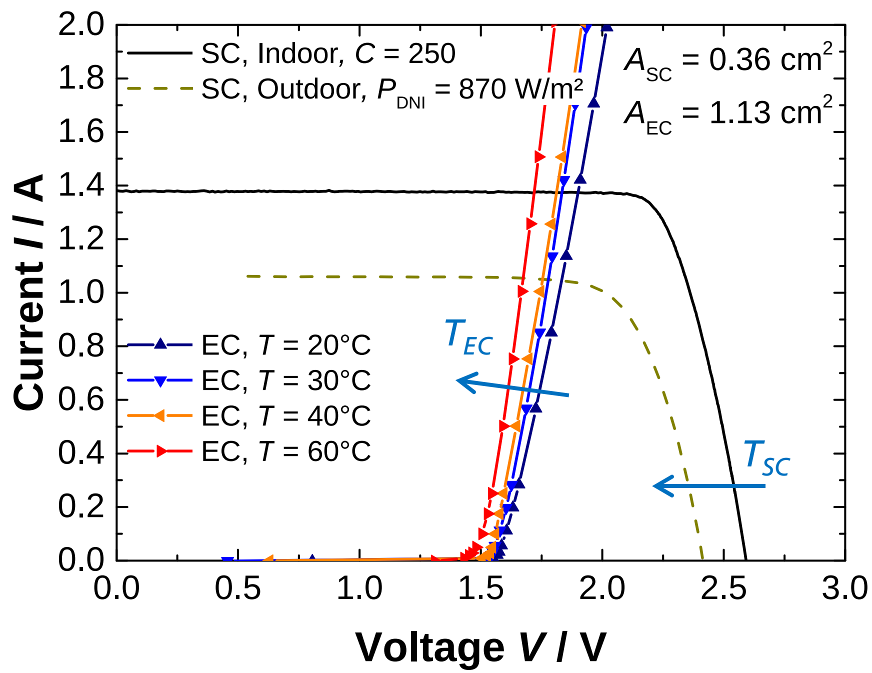
J. Ohlmann, J.F. Martinez Sanchez, D. Lackner, M. Steiner, A. Fallisch and F. Dimroth, 12th International Conference *Concentrator Photovoltaic Systems, 25.-27 April 2016*

DNI : Direct Normal Irradiance

Fraunhofer ISE

Introduction to the Hydrogen Concentrator
Operation point of a HyCon module

- Higher irradiance P_{DNI} generates higher current
- Higher temperature T_{SC} decreases voltage of solar cell
- Difference between indoor and outdoor measurement mainly due to optical losses of the Fresnel lens
- Operation point defined by cross section of *IV* curves
- Temperature effects are hardly to predict



IV curves of triple-junction solar cell and a PEM WE cell at different temperatures

DNI : Direct Normal Irradiance

Fraunhofer ISE

Introduction to the Hydrogen Concentrator
How is defined the efficiency of a HyCon module?

- Efficiency of the solar cell (SC)

$$\varepsilon_{\text{CPV}} = \frac{V_{OP} \cdot I_{\text{OP}}}{A_{\text{Lens}} \cdot P_{DNI}}$$

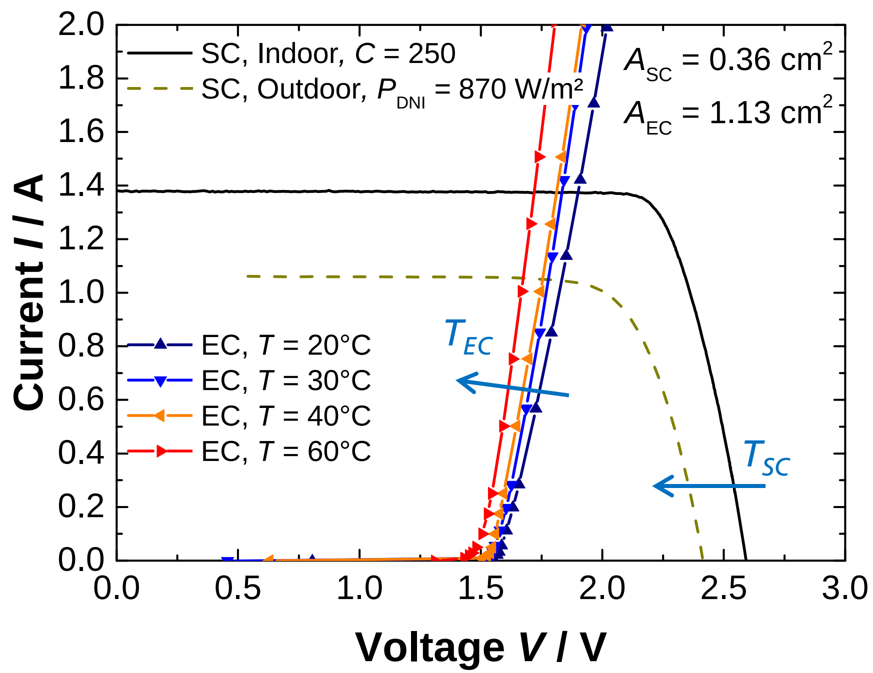
- Efficiency of the electrolysis cell (EC)

$$\varepsilon_{\text{EC}} = \frac{V_{th}}{V_{OP}} \cdot \varepsilon_F$$

- Efficiency of a HyCon module

$$\varepsilon_{\text{HyCon}} = \varepsilon_{\text{F}} \frac{V_{\text{th}}}{V_{\text{OP}}} \frac{V_{\text{OP}} I_{\text{OP}}}{P_{\text{DNI}}} = \varepsilon_{\text{F}} \frac{V_{\text{th}} I_{\text{OP}}}{P_{\text{DNI}}}$$

→ To maximise HyCon efficiency the current has to be maximised!



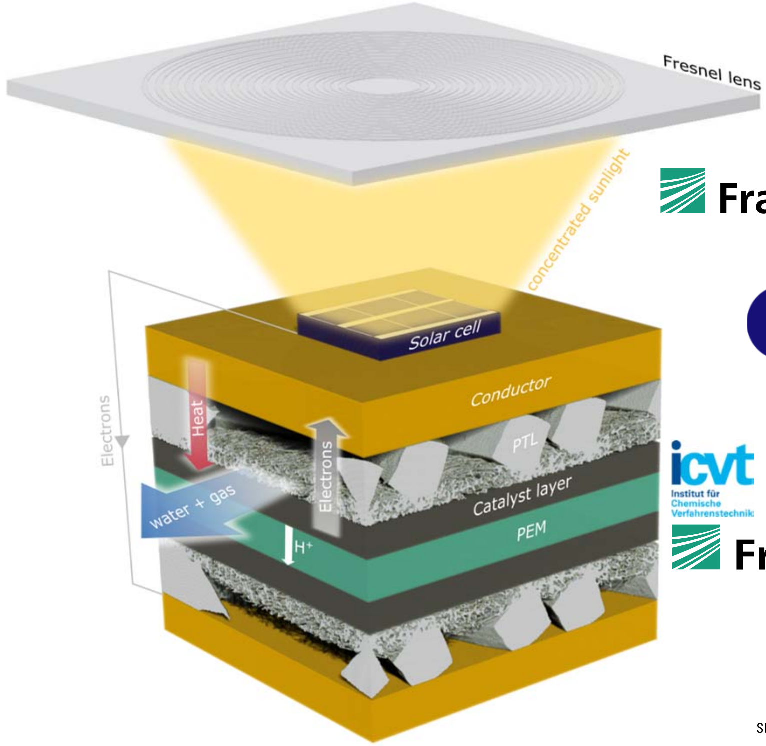
IV curves of triple-junction solar cell and a PEM WE cell at different temperatures

DNI : Direct Normal Irradiance

Fraunhofer ISE

Introduction to the Hydrogen Concentrator
German funded HyCon project

- Project duration: 11/2012 - 09/2016
- Coordination: Fraunhofer ISE
  - Design of solar cells and PEM WE cells and system layout
- Further project partners:
  - ICVT Stuttgart
    → Membrane development
  - Fraunhofer ICT
    → Catalyst development
  - IMTEK Freiburg
    → 3D reconstruction of porous transport layers (PTL) and simulation



Schematic view of a HyCon module

Fraunhofer ISE

IMTEK

icvt Institut für Chemische Verfahrenstechnik

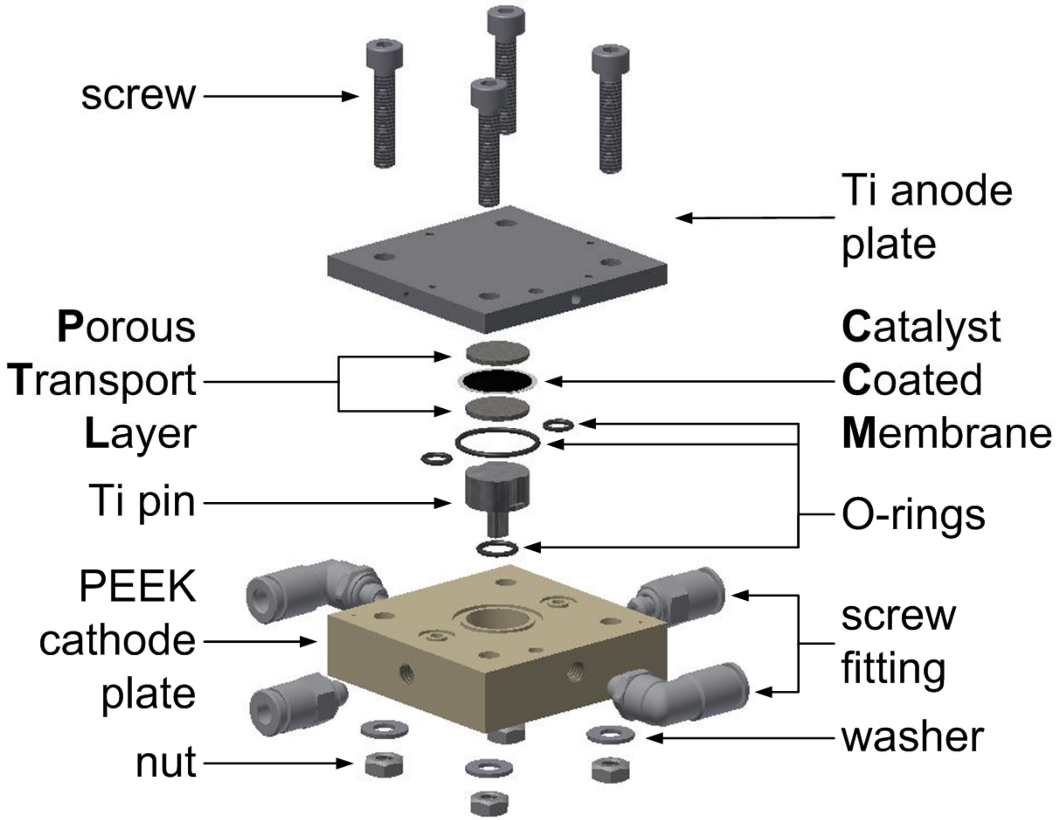
Fraunhofer ICT

SPONSORED BY THE
Federal Ministry of Education and Research

A. Fallisch et al, International Journal of Hydrogen Energy, submitted 10/2016

PEM water electrolysis cells
Cell design adapted for the HyCon module

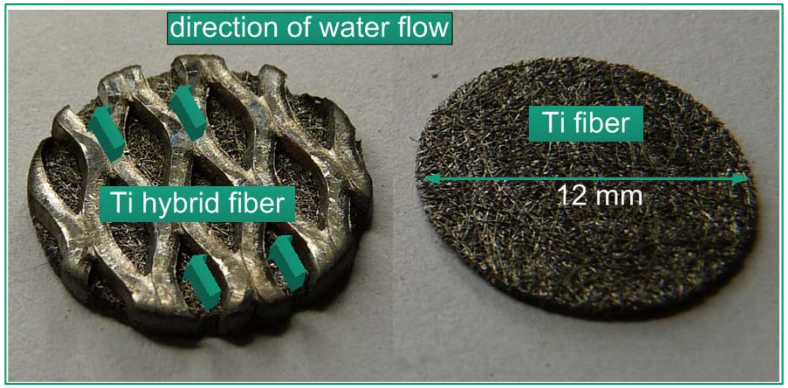
- Adaption of cell design for optimised performance
  - Thin Ti anode plate for thermal and electrical conduction
  - No flow field used
  - Natural convection prefered
  - Investigation on different PTLs and contact pressures
- Not optimised in terms of production technologies!

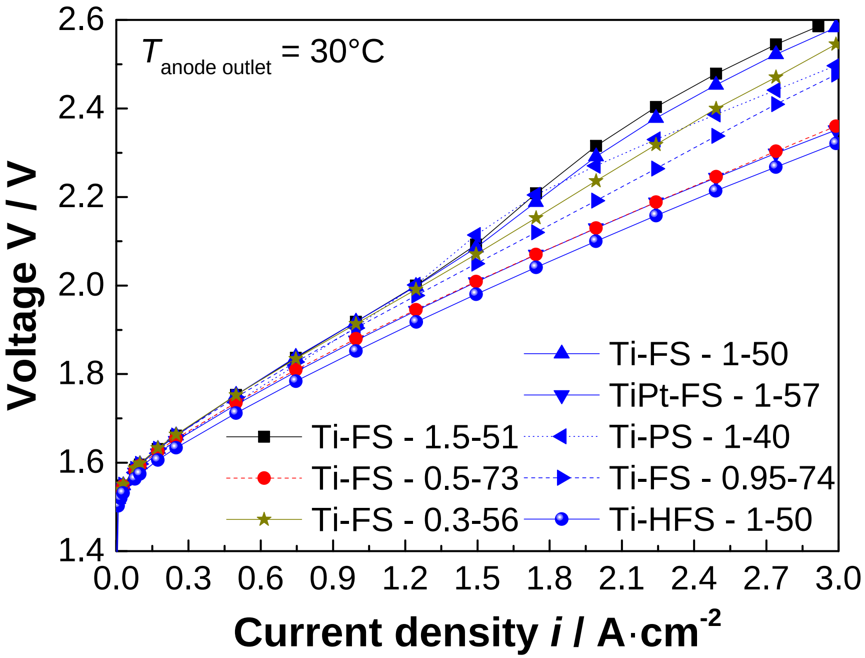


Exploded view of PEM water electrolysis cell

PEM water electrolysis cells
Evaluation of different porous transport layers

- Porous transport layer (PTL) is crucial in terms of performance and costs
- Different Ti PTLs (sinters, fibres, meshes) were test in a HyCon EL cell
- Hybrid fiber (mesh + fibre) showed best trade off in terms of
  - Performance & flow pattern

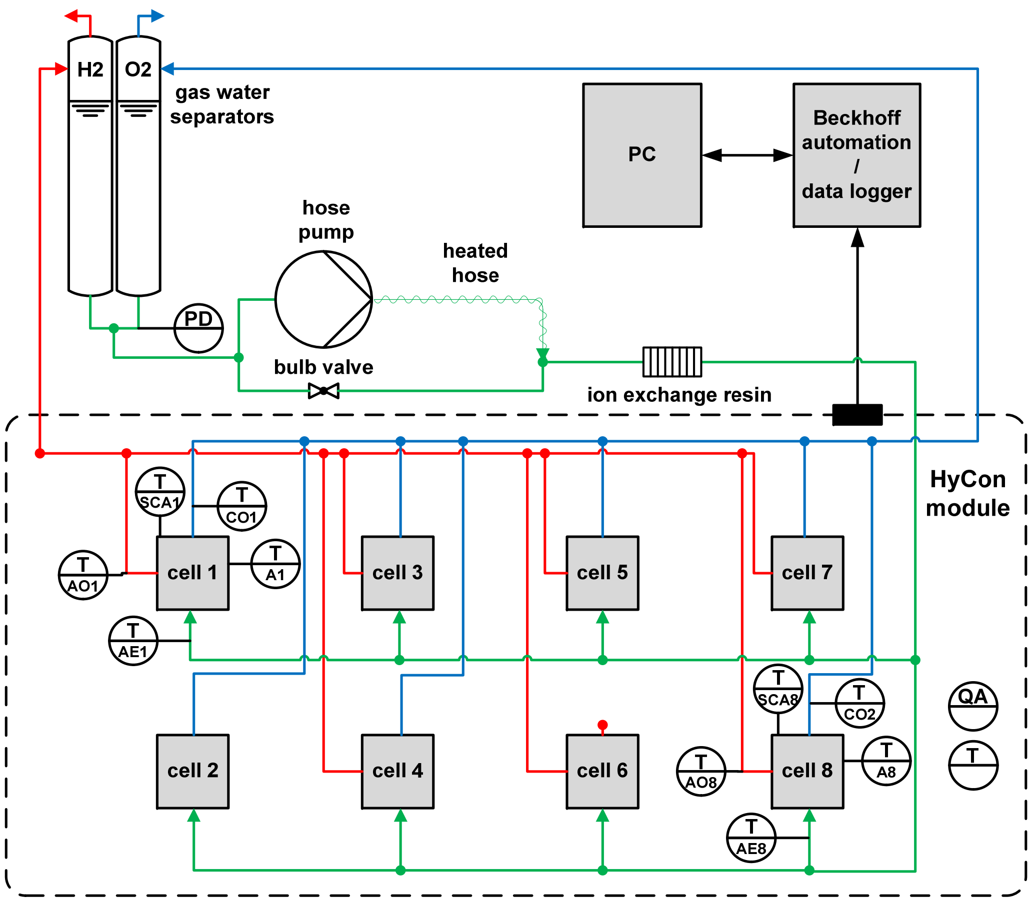




Polarisation curves using different PTLs, all measured with commercial MEA

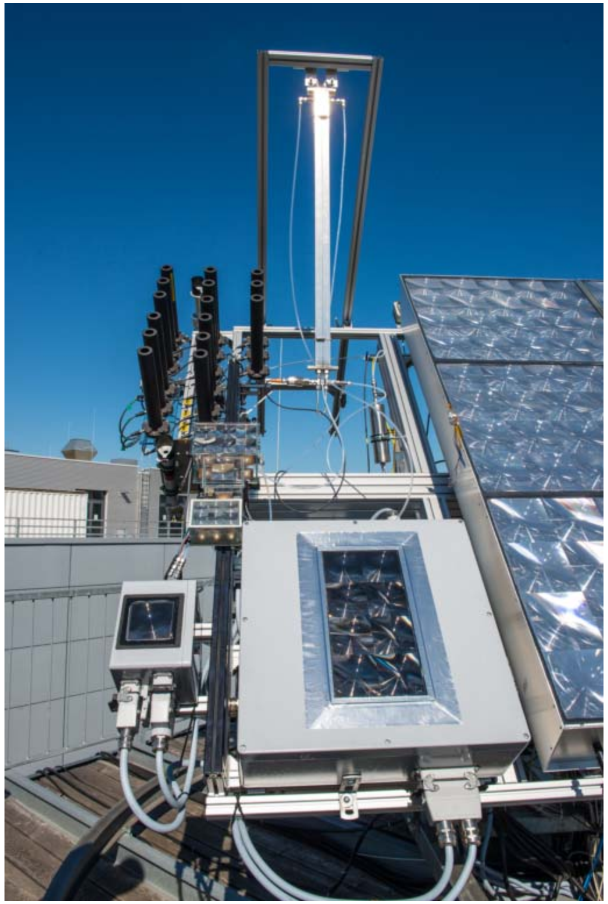
HyCon Demonstrator for Outdoor Testing
System design

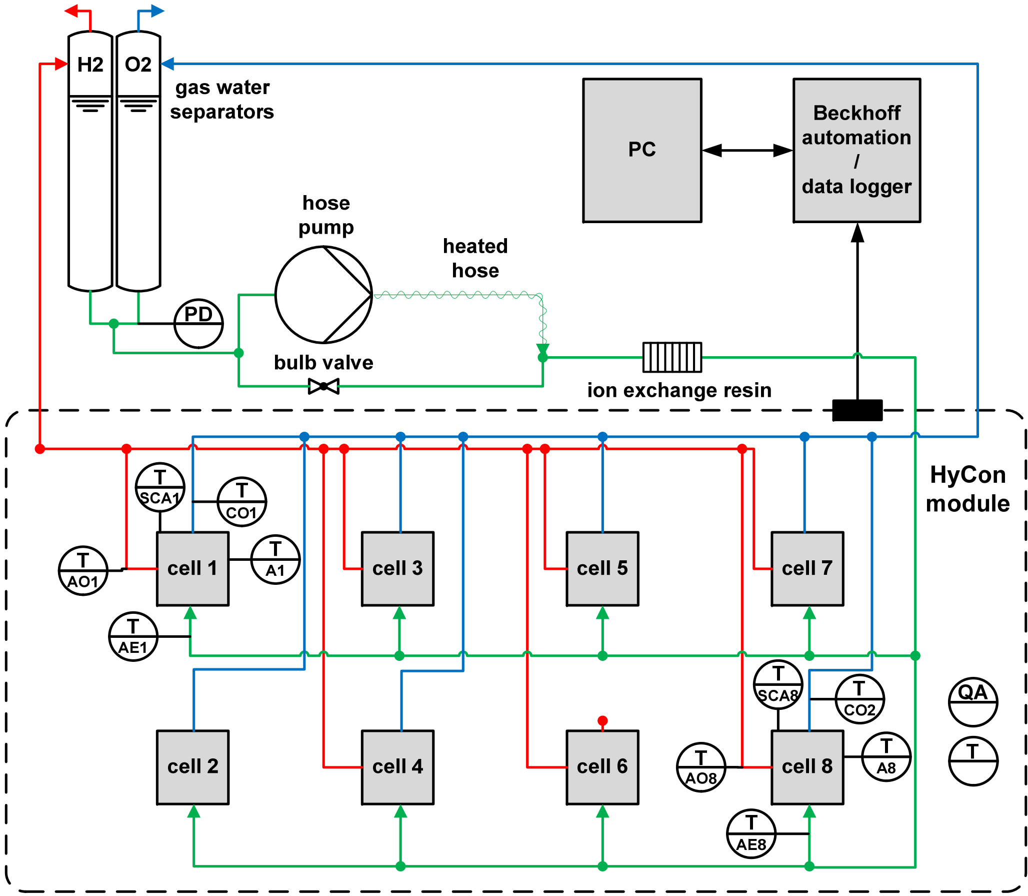
- HyCon demonstrator for outdoor measurements in Freiburg /Germany
  - 8 HyCon modules
  - Weatherproof packaging
  - Mounted on a two axis PV tracker
  - Switching between forced and natural convection possible
  - Field test in 07.-09.2016
  - Comprehensive monitoring of all relevant parameter



Fraunhofer ISE

HyCon Demonstrator for Outdoor Testing
System design

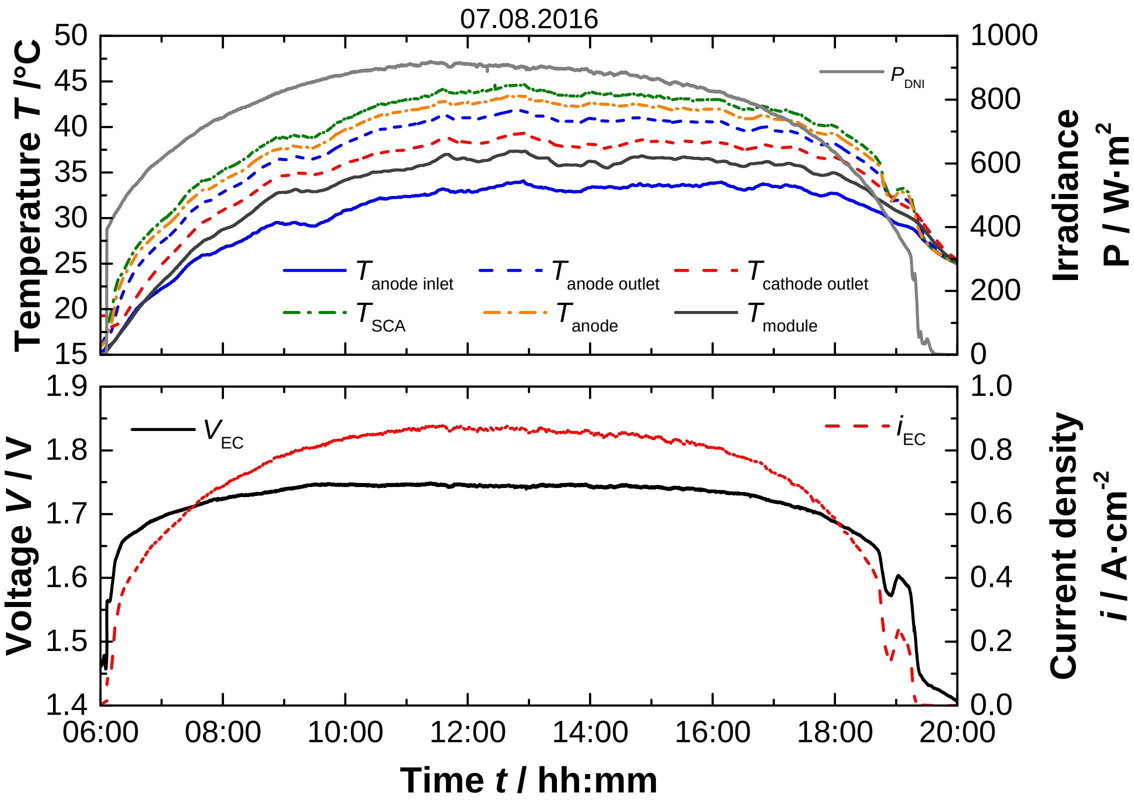




Fraunhofer ISE

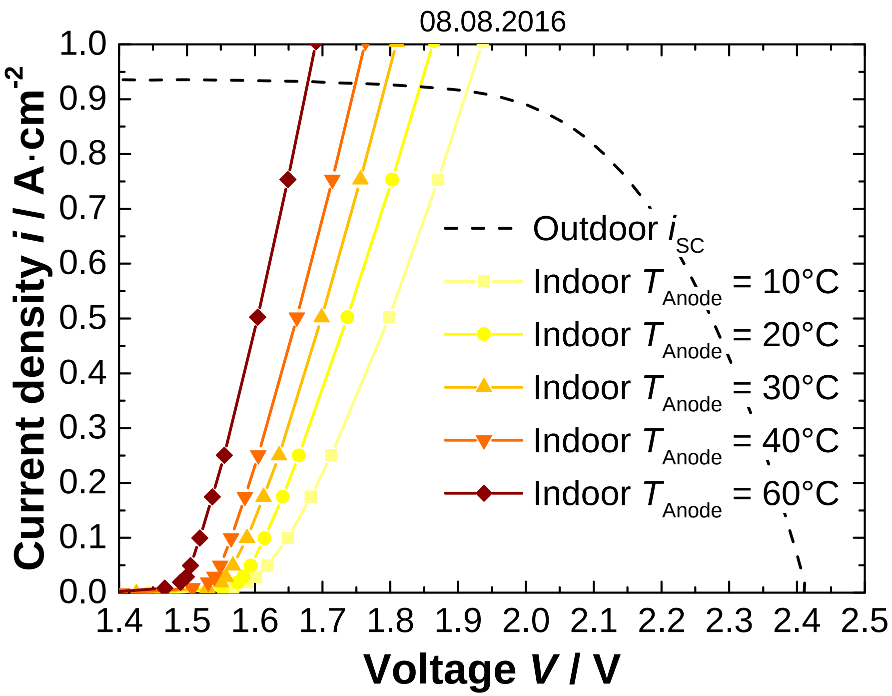
HyCon Demonstrator for Outdoor Testing
Typical behaviour of a HyCon module over the day

- HyCon module 1 during course of the day
- Forced convection
- Current density i_{EC} is proportional to irradiance P_{DNI}
- Cell voltage V_{EC} depending on i and T_{anode}
- Thermal coupling works properly
  $T_{SCA} > T_{anode} > T_{anode\ outlet} > T_{cathode\ outlet} > T_{module} > T_{anode\ inlet}$



HyCon Demonstrator for Outdoor Testing
iV-charateristic of solar and electrolysis cells

- *SC* characteristic measured in an electrical mono module on the roof
  - P_{DNI} = 870 W/m²
  - SC with 90.25 cm² lens
  - Efficiency ε_{SC} = 25.6%
- iV curves of EC measured indoor at different temp.

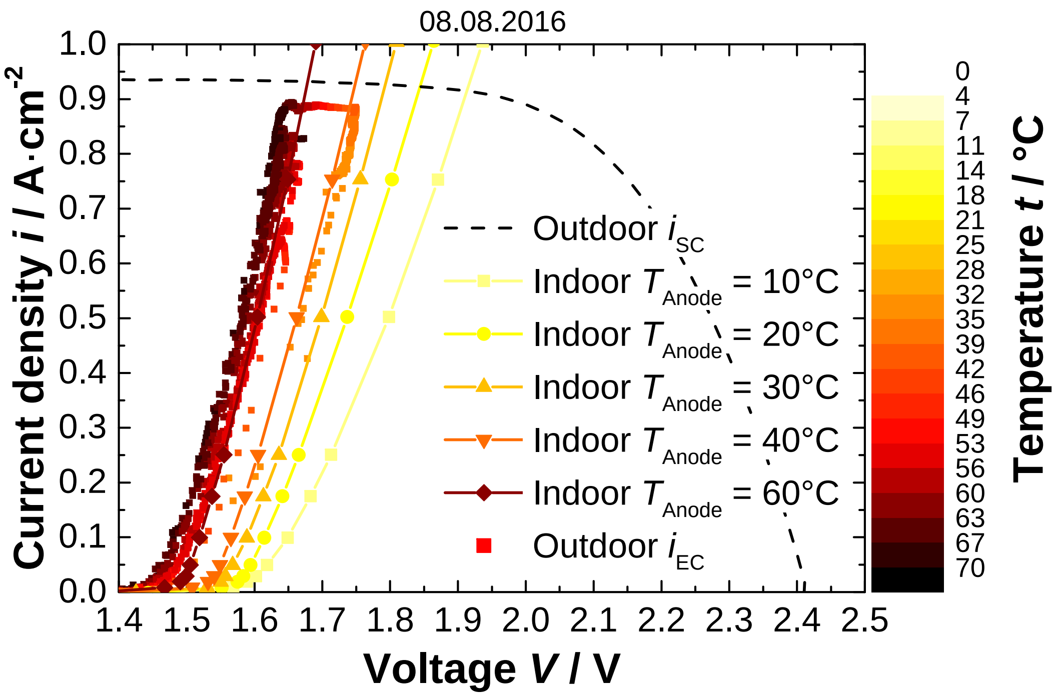


Fraunhofer ISE

HyCon Demonstrator for Outdoor Testing

iV-charateristic of solar and electrolysis cells

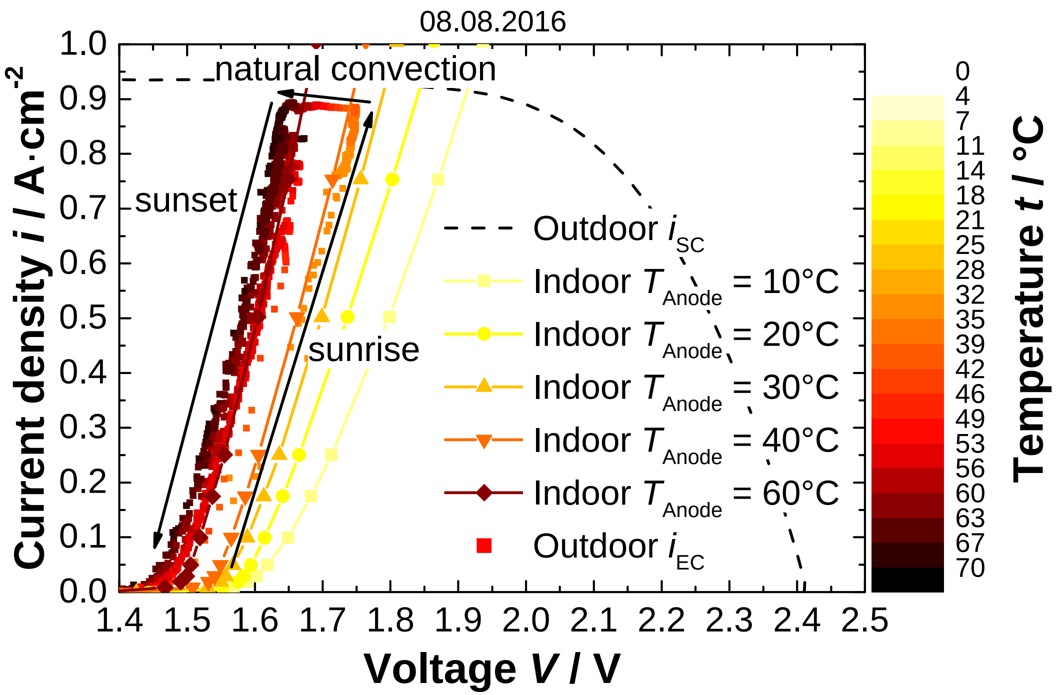
- *SC* characteristic measured in an electrical mono module on the roof
  - P_{DNI} = 870 W/m²
  - SC with 90.25 cm² lens
  - Efficiency ε_{SC} = 25.6%
- iV curves of EC measured indoor at different temp.
- Good correlation between indoor and outdoor polarisation curves



Fraunhofer ISE

HyCon Demonstrator for Outdoor Testing
iV-charateristic of solar and electrolysis cells

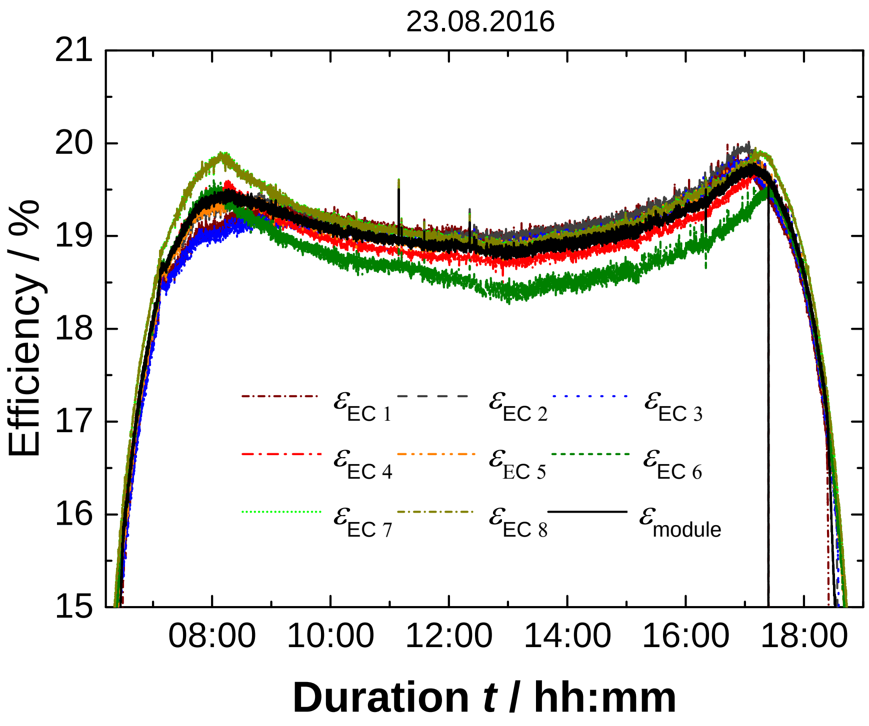
- *SC* characteristic measured in an electrical mono module on the roof
  - P_{DNI} = 870 W/m²
  - SC with 90.25 cm² lens
  - Efficiency ε_{SC} = 25.6%
- iV curves of EC measured indoor at different temp.
- Good correlation between indoor and outdoor polarization curves
- Turning off the pump leads to temperature increase



Fraunhofer ISE

HyCon Demonstrator for Outdoor Testing
Efficiency over the day

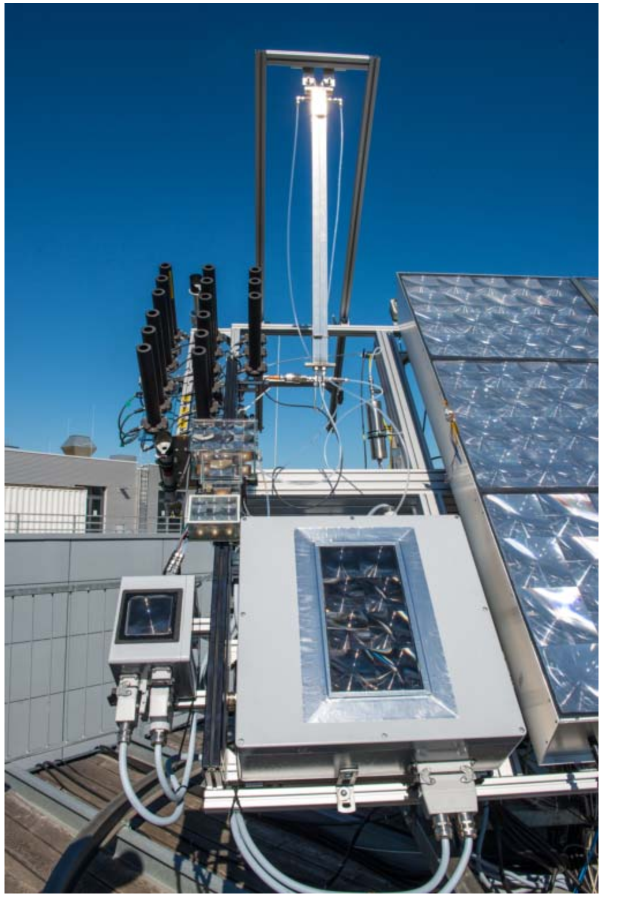
- Faraday efficiency measured indoor to be above 98.5% for current densities i > 0.8 A/cm^2
- Highest efficiencies in the morning and evening due to solar spectrum
- HyCon module efficiency above 19% for more than 6 h and 20% efficiency for one module achieved



Fraunhofer ISE

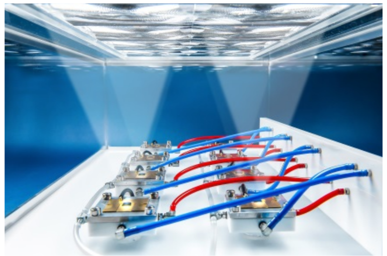
Summary

- The HyCon module is a highly efficient generator to produce „directly" hydrogen from sun light
- Proper design of solar and electrolysis cells is required to meet optimised operating point
- First demonstrator world wide consisting of 8 HyCon modules tested in an outdoor field test
  - Thermal management succesful integrated
  - Operation under natural convection possible
  - Module efficiency close to 20% is achieved



Fraunhofer ISE

Acknowledgements



- All members of the departments "Chemical Energy Storage" and "III-V - Epitaxy and Solar Cells" at Fraunhofer ISE

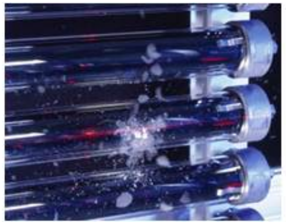
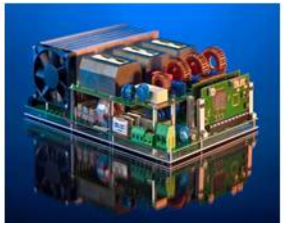
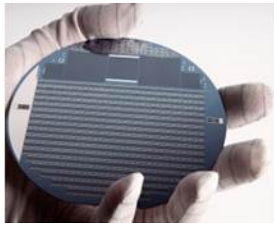
SPONSORED BY THE

Federal Ministry of Education and Research

- This project has been funded by the German Federal Ministry of Education and Research (BMBF) under the contract number 03SF0432A

Fraunhofer ISE

Thank you for your attention!

Fraunhofer Institute for Solar Energy Systems ISE

Dr. Tom Smolinka

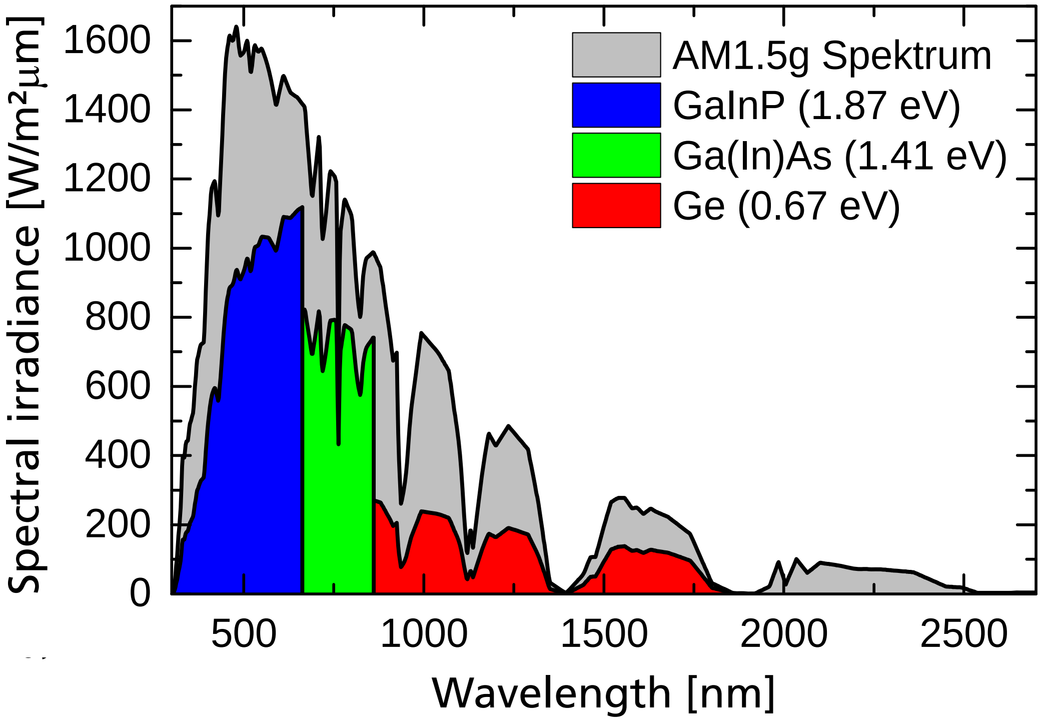
www.ise.fraunhofer.de

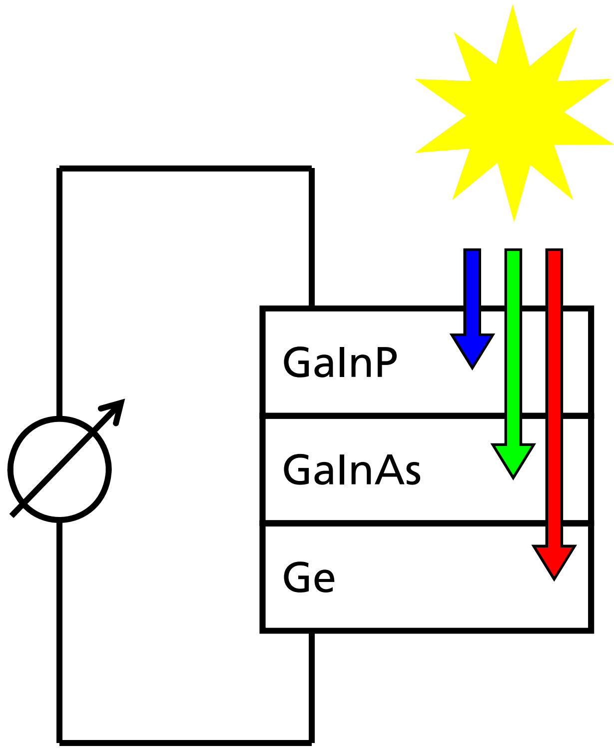
tom.smolinka@ise.fraunhofer.de

Fraunhofer ISE

Introduction to the Hydrogen Concentrator

Why multi-junction solar cells?





- Cell made of III-V compound semiconductors by stacking three single-junction cells
- Each cell converts efficiently a limited spectral bandwidth of sunlight to electricity