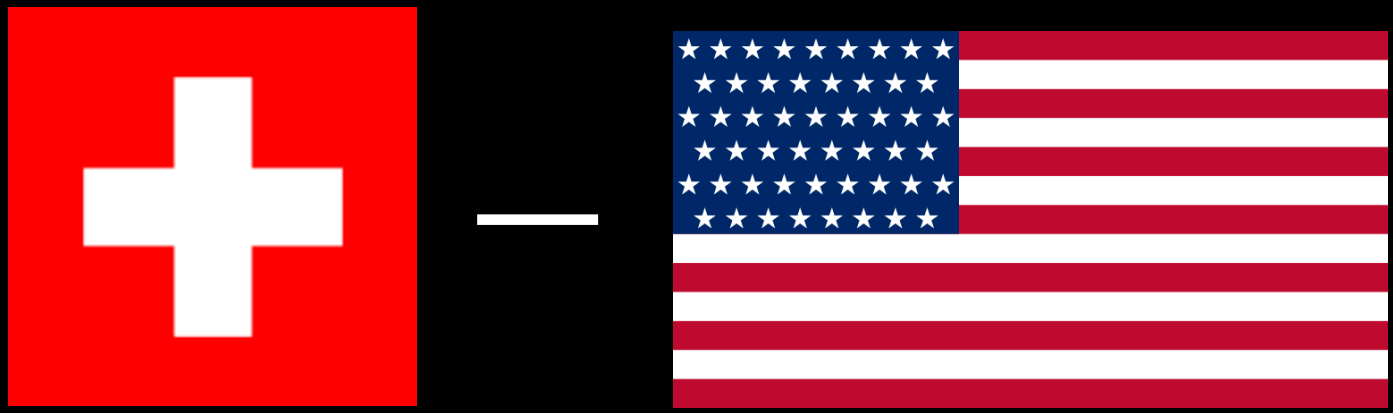
Novel designs and materials for durable PV modules: applications on the ground, in cities and in the air

Prof. Christophe Ballif
EPFL, Director Photovoltaics and thin film electronics laboratory
CSEM, Director CSEM PV-center

Neuchâtel

IEEE PVSC, Washington 2017



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AMERICA FIRST
SWITZERLAND SECOND

Switzerland

- Meyer Burger
- Pasan
- Multi-contact
- ABB
- Indeotec
- Megasol
- Oerlikon Solar/Tel
- Flexcell
- …
- ….

Switzerland:

Should exit Nuclear
(5 power plants)
by 2035…. Or later…

Potential of PV: taken seriously only today !

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Politics: mportant to reach 12-15 GW installed…

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Swiss people voting on 21th of Mai 2017
on new energy strategy

-> need for 12 GW of PV by ~2035

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!! Meaning of the survey

Two weeks before the energy vote: 55% for, 45% against

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! Meaning of the survey !

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Results vote

- 58% yes and 42% No

Switzerland first country with people voting for

- More energy efficiency
- More renewable
- Less CO2

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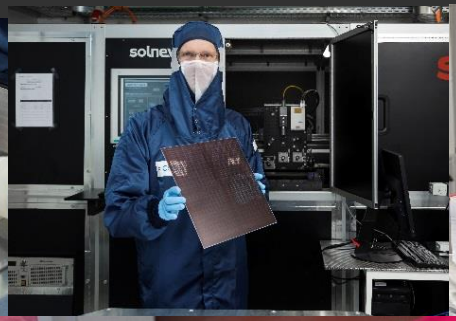
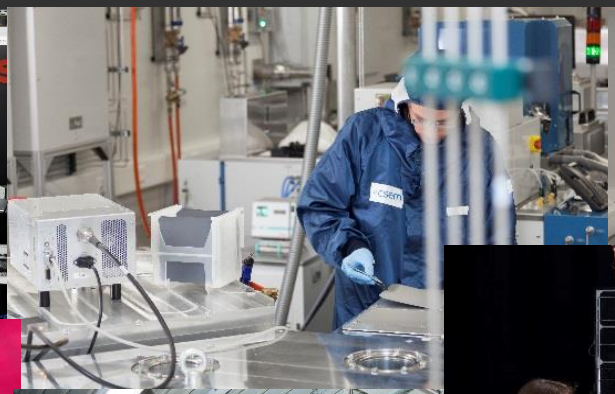
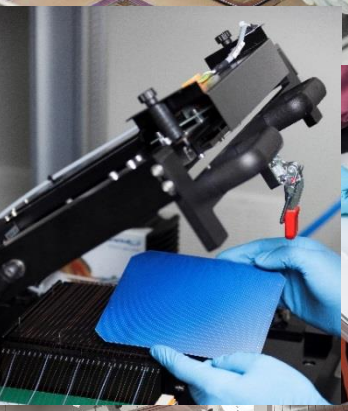
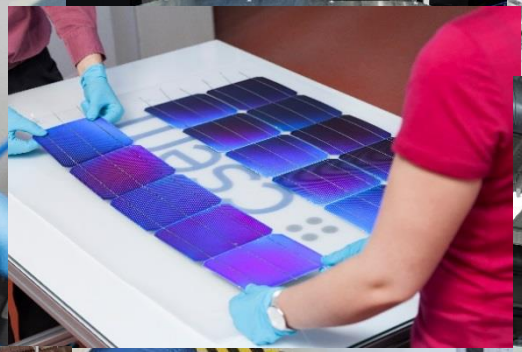
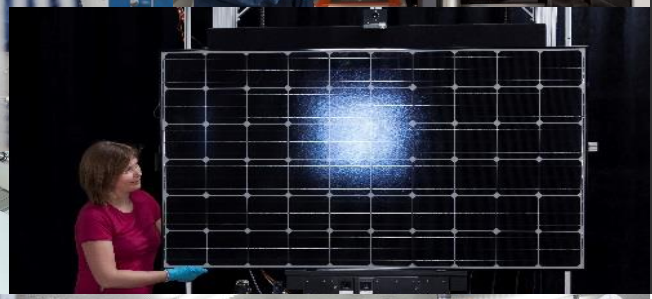
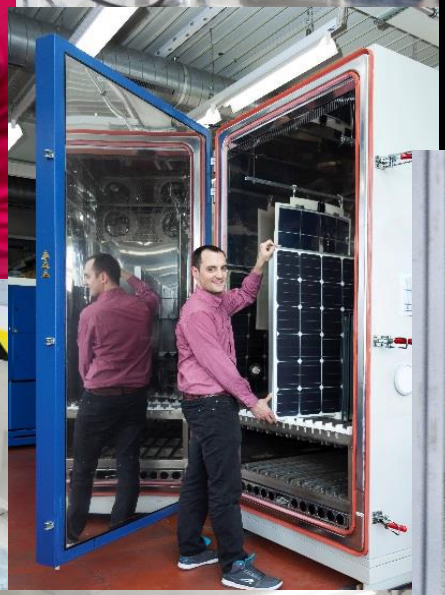
2000 m2 research and piloting… Contracts with over 40 companies along the chain





Polymer compounding for high reliability: platform for PV packaging materials

- Packaging foil of 0.1 to 2.5 mm thick and width of 20 cm
- Compounder / pelletizer (capacity: 4 Kg/h)
- Flat cast film extrusion / chill roll (capacity: 10kg/h)

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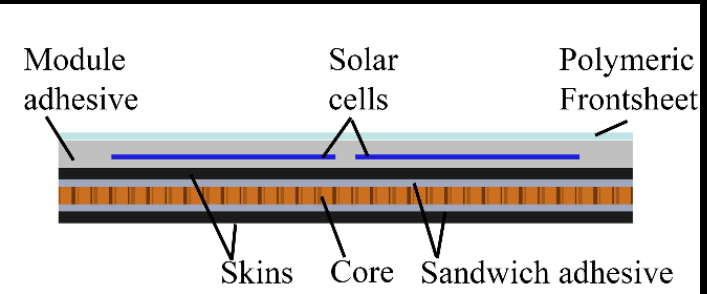
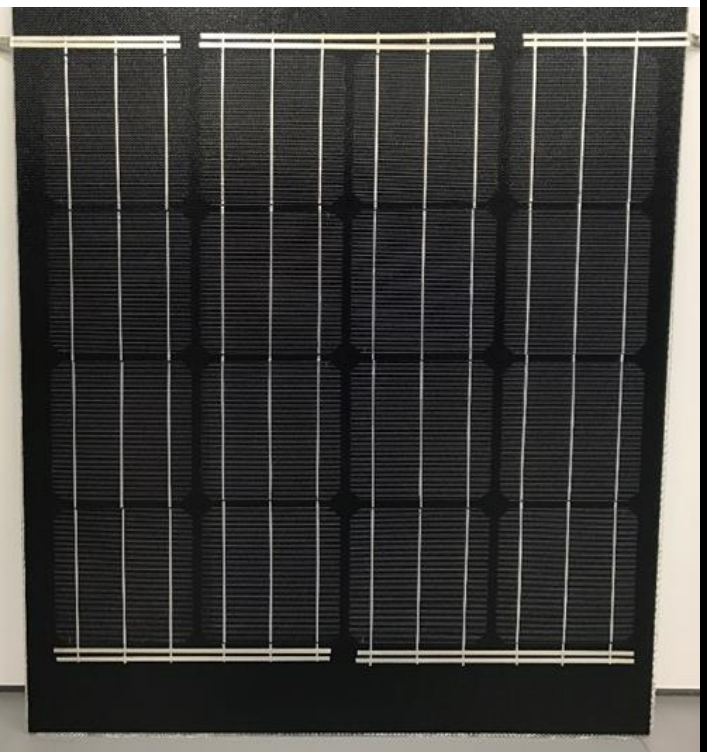
Light weight, hail resistant modules
A. Martins, A. Virtuani
Area 8, 2h30 today





Arnaud Walter et al.
16% perovsite single junction modules
Area 6 1630, today

P. Löper,
Passivated contacts,
Area 4, 16 Today

J. Werner
Perovskite/Silicon Tandem Solar Cells
tomorrow 2h45

Stephanie Essig >32.5%
efficient III-V/Si dual-junction solar cells and > 35% triple junction, tmorrow 15h

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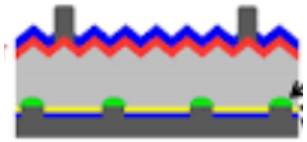
Power pure : Trends in mainstream crystalline PV

- diamand Wire sawing for mono
- Thinner mono
- HHP multi



Al-BSF
→ PERC

N-PERT, SHJ

IBC

- More busbars
- Glass-Glass

- Wires/multi-wires
- Half-cells
- Shingles
- MWT

- Single-axis tracking
- 1500 V
- Bifacial

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Commercial products

666 mV
77.3% FF
18.3% efficient

State of the art p-type PERC Mono (typ 305 W)

LG NeON™ 2

LG320N1C-G4 | LG315N1C-G4
LG310N1C-G4 | LG305N1C-G4

60 cell

LG's new module, NeON™ 2, adopts Cello technology.
Cello technology replaces 3 busbars with 12 thin wires to enhance power output and reliability.
NeON™ 2 demonstrates LG's efforts to increase customer's values beyond efficiency. It features enhanced warranty, durability, performance under real environment, and aesthetic design suitable for roofs.

681 mV
77.9% FF
19.5% efficient

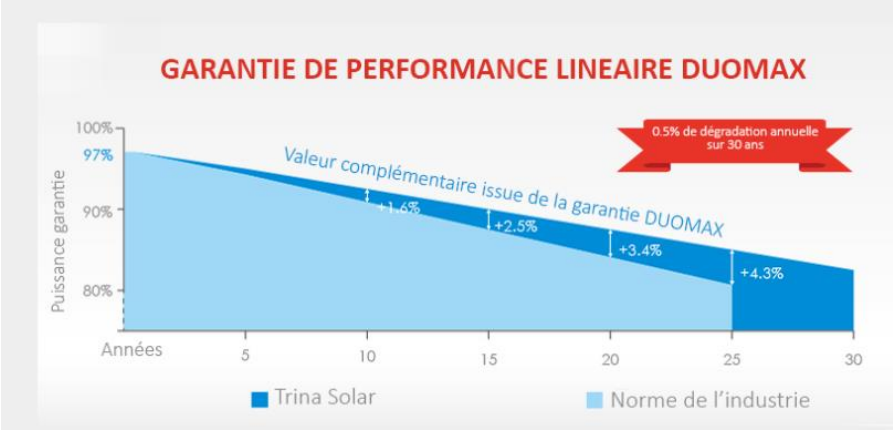
X22 SERIES

SPR-X22-360

724 mV
79.9% FF
22.2% efficient

SHJ
726 mV
78% FF
19.7% efficient

Ultra-agressive warranty



Important

- 2-4% absolute FF points losses between best cells and modules
- 10-15% absolute Efficiency losses between cells and modules (e.g. cells at 21% → module at 18.5%efficiency)

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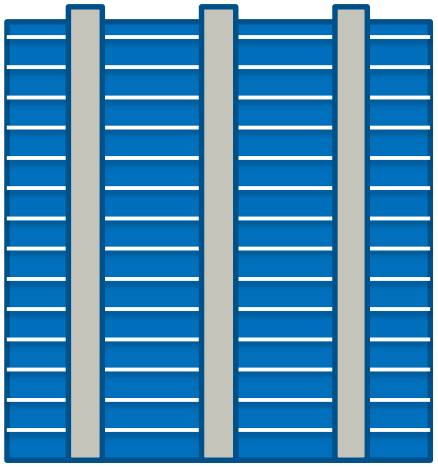
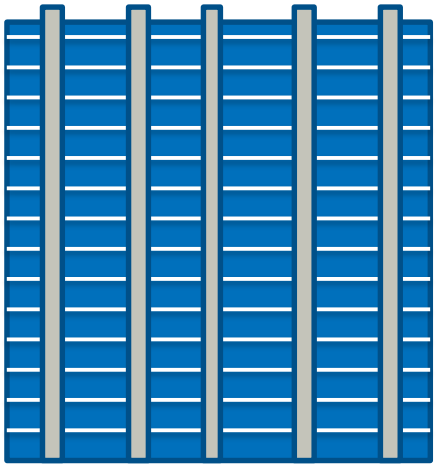
Improving metalisation and interconnection

Minor changes



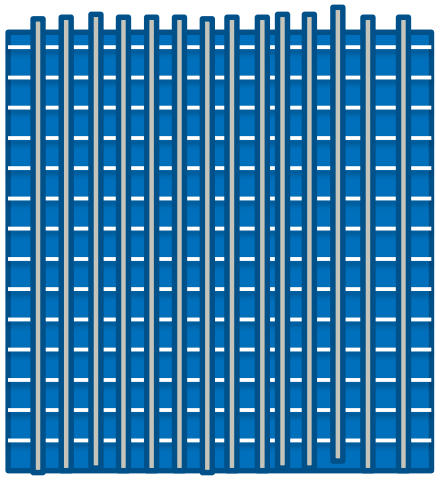


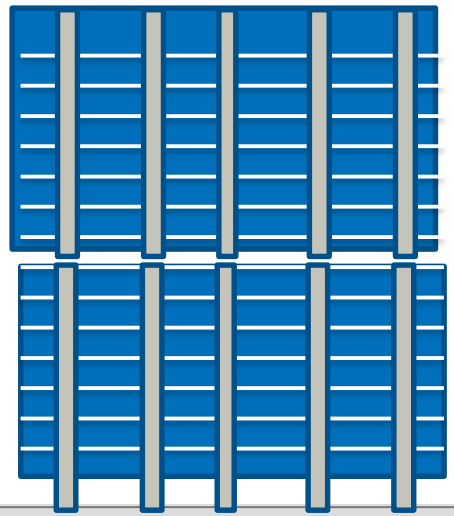
Reduced losses
In Ag fingers (FF)
And/or less Ag

+ possible optical gains:
White/texture ribbon, round wire → total internal reflection

Challenge:
Increase cross-section of Cu
Pack cell closer

Major changes





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Exemple: high voltage technology and reduction of

Energy & Environmental Science

ROYAL SOCIETY OF CHEMISTRY

PAPER

View Article Online
View Journal

Check for updates

Cite this: DOI: 10.1039/c7ee00286f

The impact of silicon solar cell architecture and cell interconnection on energy yield in hot & sunny climates†

Jan Haschke,* [a] Johannes P. Seif,[a] Yannick Riesen,[a] Andrea Tomasi,[a] Jean Cattin,[a] Loïc Tous,[b] Patrick Choulat,[b] Monica Aleman,[b] Emanuele Cornagliotti,[b] Angel Uruena,[b] Richard Russell,[b] Filip Duerinckx,[b] Jonathan Champliaud,[c] Jacques Levrat,[c] Amir A. Abdallah,[d] Brahim Aïssa,[d] Nouar Tabet,[d] Nicolas Wyrsch,[a] Matthieu Despeisse,[c] Jozef Szlufcik,[b] Stefaan De Wolf‡ [a] and Christophe Ballif[ac]

Finding: cells have always a better coefficient of T than modules !
Typically 0.05%/°C better for cells than for modules

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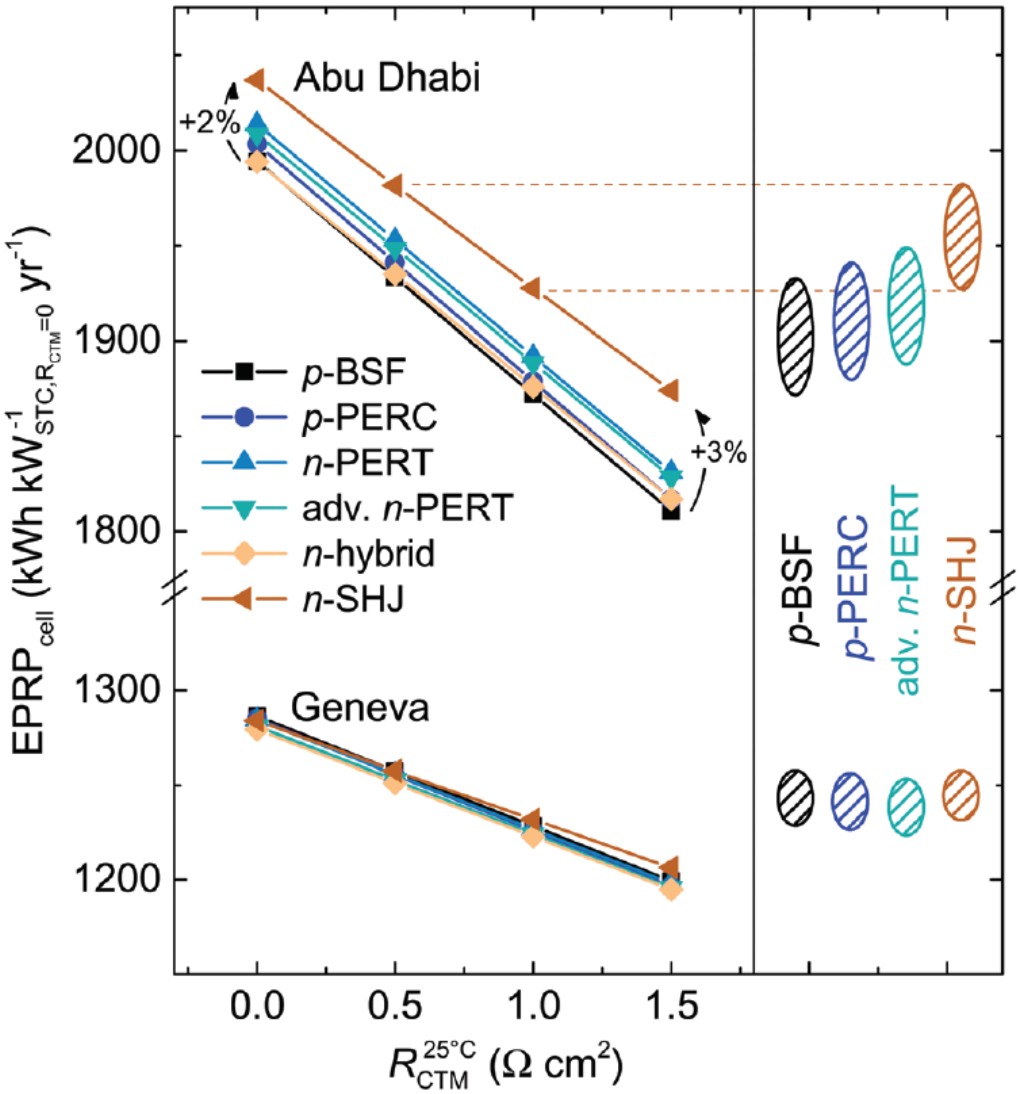
High voltage technology

- **Impact of series resistance on Tc of PMax**
- **Double Impact of cell voltage:**

- Better intrinsic Tcoeff
- Less sensitivie to Series resistance

10:45 Friday Area 4. J. Haaschke et al.

Haschke et al. EES 2017



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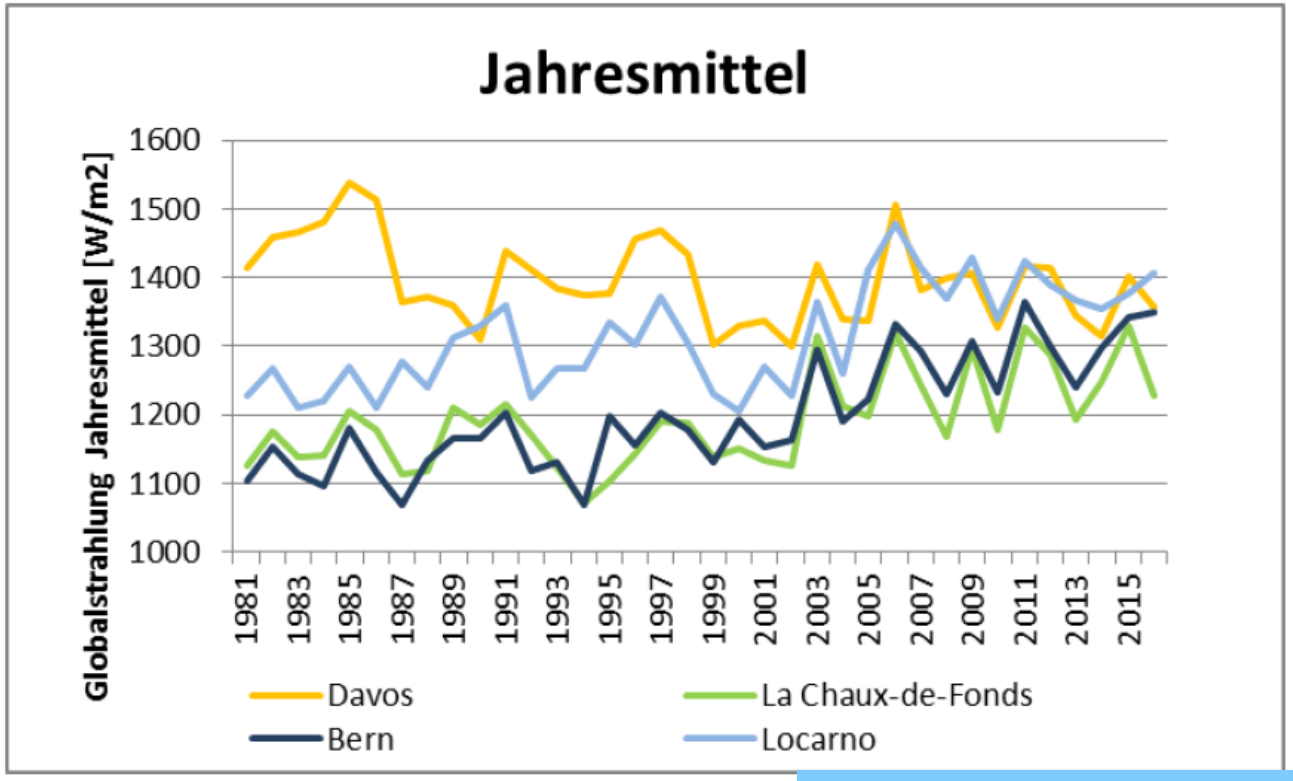
Reliability



Source.
J. Remund, Meteotest

Up to 10-15% increase in global irradiance
Over the 15 last years in parts of Switzerland/Europe

In place with «lightnening of atmosphere» degradation of modules might have been unoticed

No Fingers

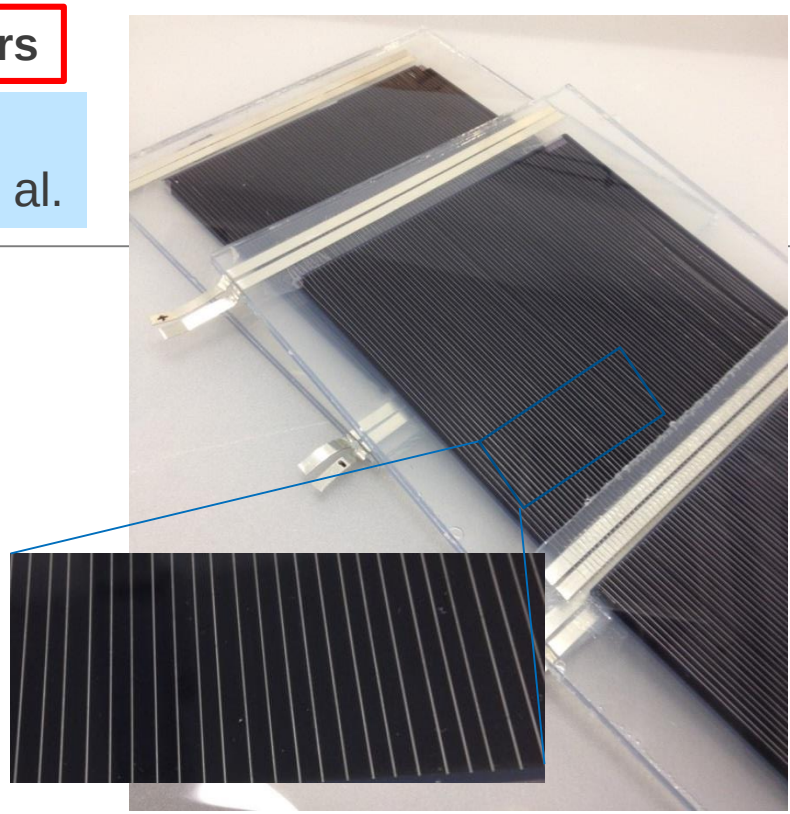
Source
A. Faes et al.

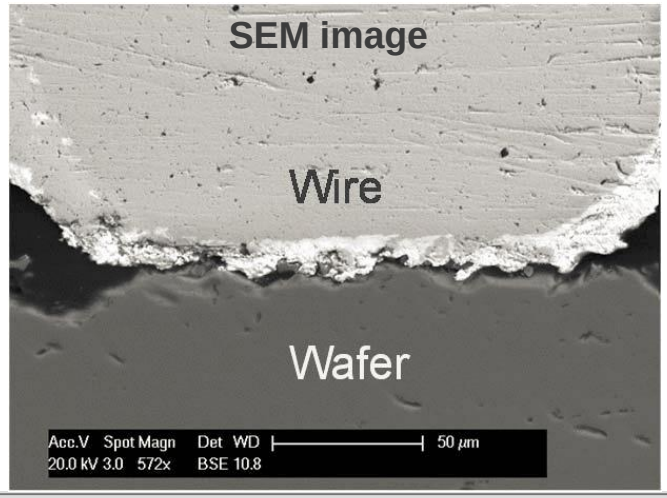
No Metallization: only wire

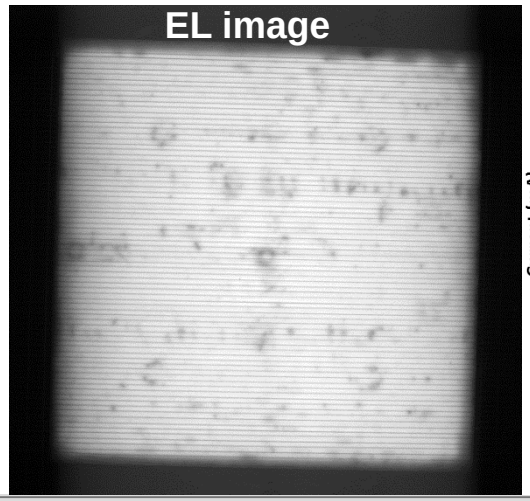
- Direct contact between InSn wire coating and TCO from the cell

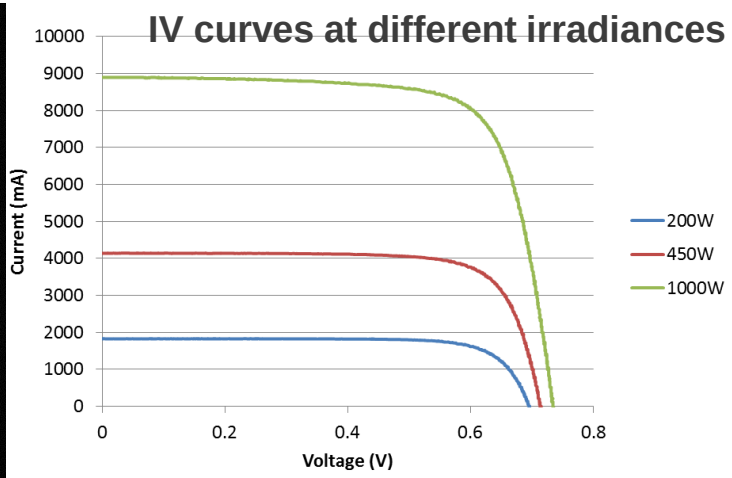
Irradiance	Voc (V)	Jsc (mA.cm^{-2})	Module eff (%)	FF (%)
200 W/m^2	0.696	7.73	20.6	77.8
450 W/m^2	0.714	17.40	20.7	76.5
1000 W/m^2	0.734	37.30	**19.9**	74.0

Module without metallization at 19.9 % eff.









CSEM acknowledge Choshu Industry Co for cell precursors

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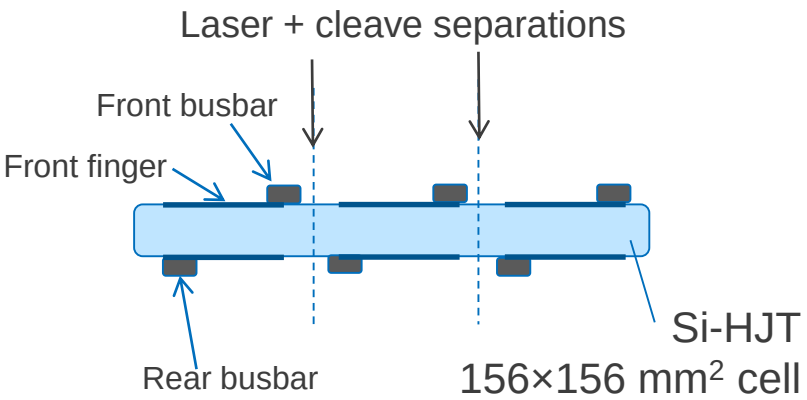
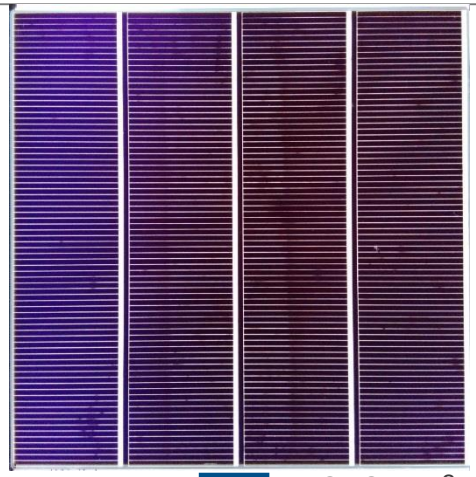
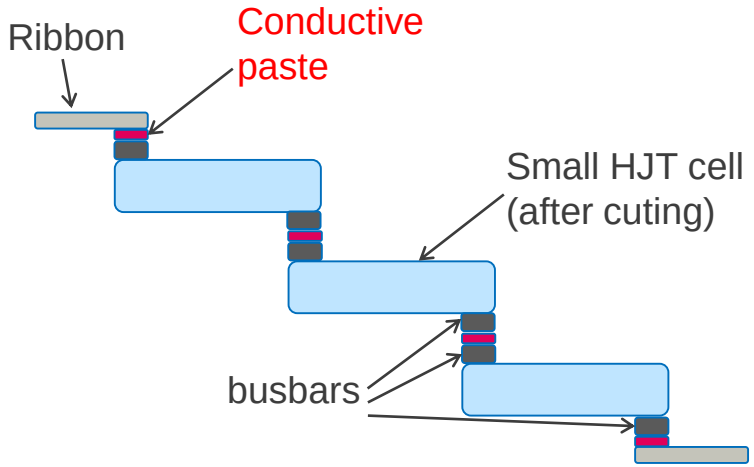
No Ribbons nor Wires

Source
A. Faes et al.

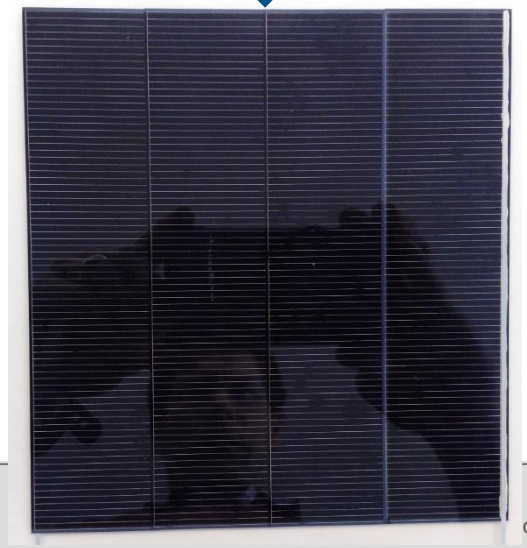
Module with Shingle Cell Interconnection: reducing the optical losses



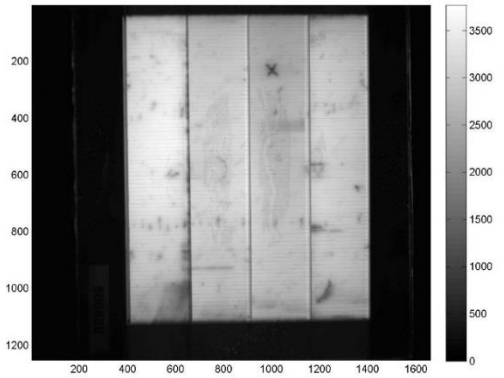




229 cm²



CTM losses	Eff da (%)	Power (%)
	+1.5%	-4.2%



21% module efficiency
Pass 400TC

Smart-wire Motivation

MEYER BURGER

- High module power
  - Light coupling from round wires
  - Increased Cu cross section area
- Silver saving

  No busbar, no solder pads

  Fine fingers/Low Rs
- Versatile design

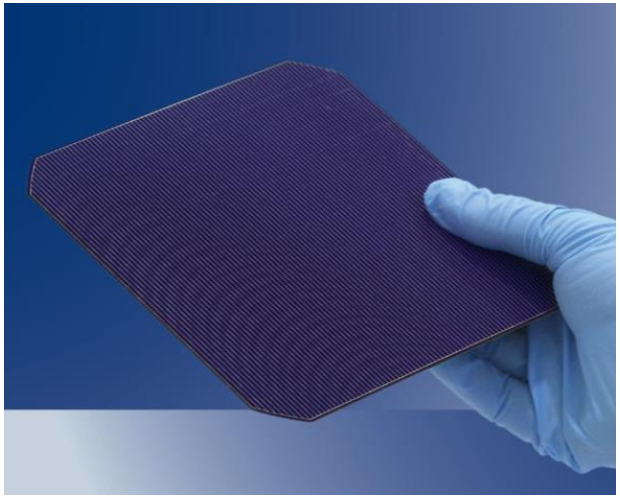
  Monofacial PERC cell

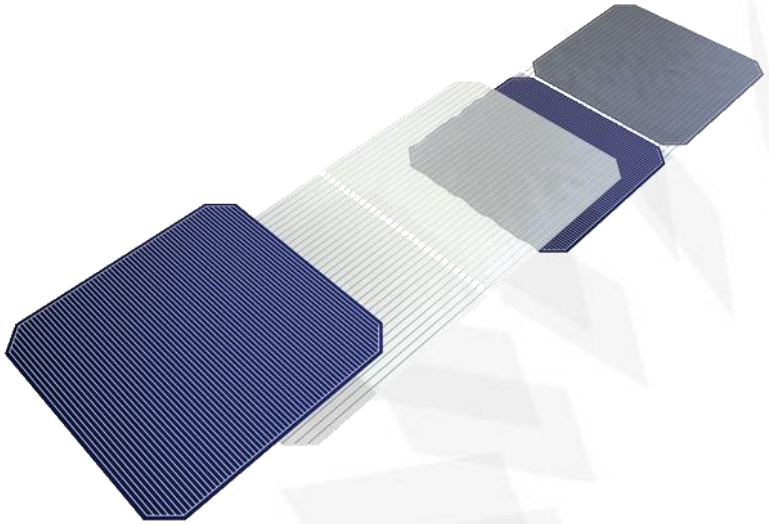
  Bifacial PERC, PERT, HJT cell

  Half-cell

  Thin wafer compatible

  GBS, GG





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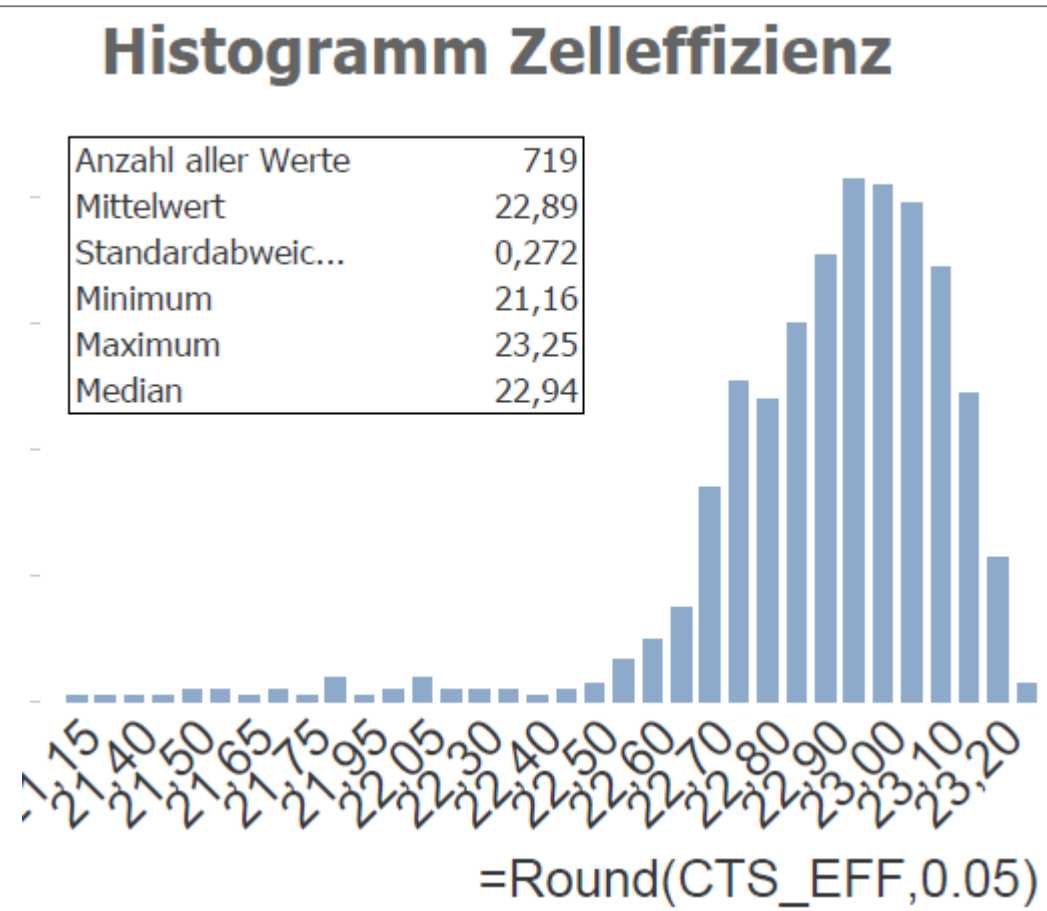
Improvement in Heterojunction and multi-wire



Pilot line Meyer Burger (D)
Results 15 days ago on
719 Cz-wafer, standard wafers
Black Chuk measurement
Grid Touch measurement
22.94% average eff

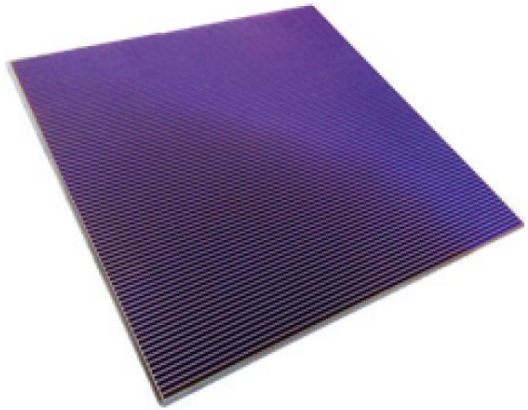
Average FF, 82%, Voc=735, Current 9.31 A

Courtesy Jun Zaho, MBT

Cell measurement «smart-wire» with grid touch

- **Measurement without shading of wire (→ effecting shadowing of 2.25% in module),**
- **No wire RS loss (→ 3% FF loss in module) →**

~ 22% busbar bificial cells measured on Black chuck with contact at extremity of wires.



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300 mu Indium free
SWCT certified @ IEC 2016

Courtesy T. Söderström, MBT

MEYER BURGER

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Precisely Right.

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Energy and Environmental Technology

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Switzerland

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Mail cox@de.tuv.com
Web www.tuv.com/pv
Cologne, 13 April 2017

Declaration on IEC testing
No. 21237732-1

Manufacturer: **Meyer Burger AG**
Schorenstrasse 39
3645 Gwatt (Thun)
Switzerland

PV-modules: "Bifacial 290"
With materials and design laid down in project 21237732.
(Bificial glass/glass(2mm) design, Silicon heterojunction solar cells (HJT),
Smartwire cell interconnection technology with Indium-free metallization,
First Enlight encapsulant, frameless,)

Herewith it is declared, that all laboratory tests for the certification acc. to the new standards IEC 61215:2016 and IEC 61730:2016 have passed without failure.

Business Field Solar Energy

ppa. Dipl.-Ing. W. Vaaßen

i. A. Dipl.-Ing. A. Cox

TC	Voc	Isc	Pmax	FF [%]	ΔPower (%)
0	43.9	8.84	300.8	77.6	0.0%
109	44.0	8.86	300.3	77.0	-0.2%
347	44.0	8.87	299.2	76.6	-0.6%
DH	43.7	8.8	295.3	76.8	
1000	43.8	8.7	292	76.4	-0.6%
2000	43.7	8.8	291.9	75.8	-1.3%

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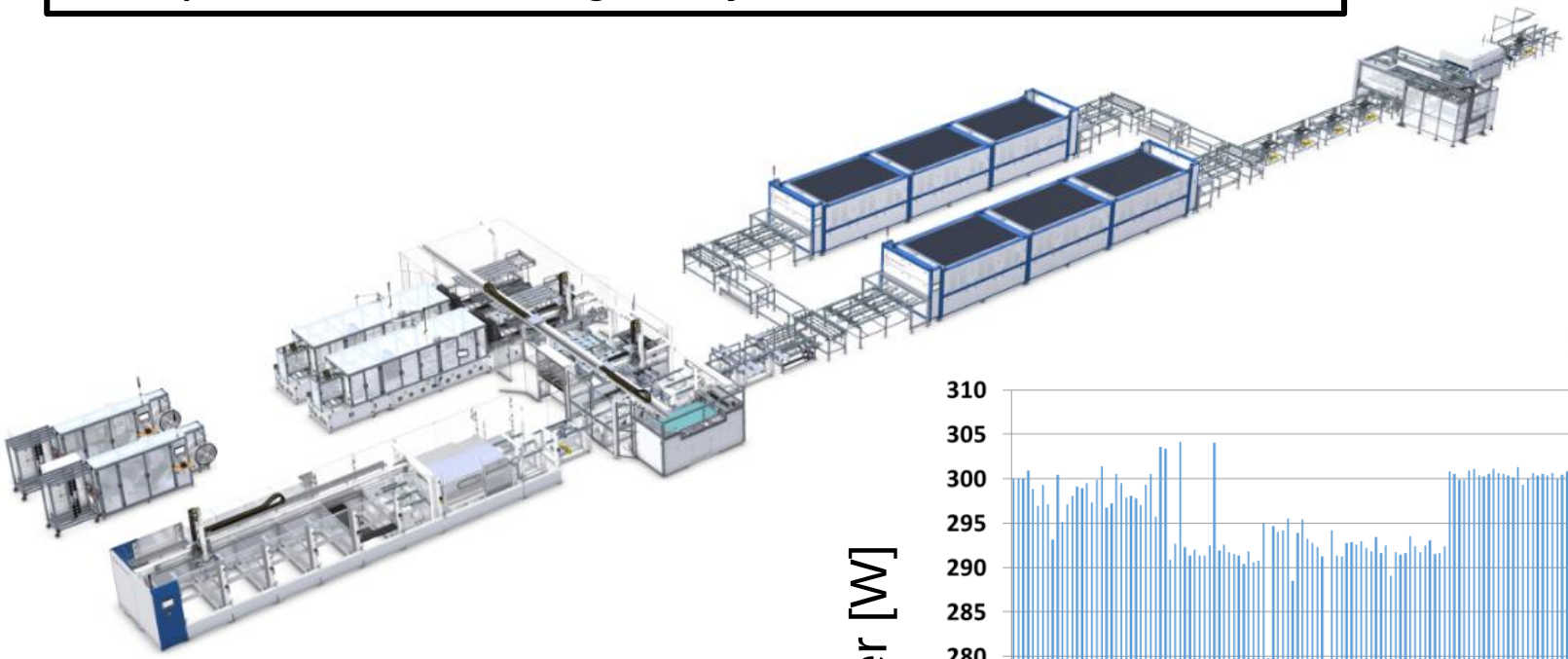
Web www.tuv.com/solarenergie

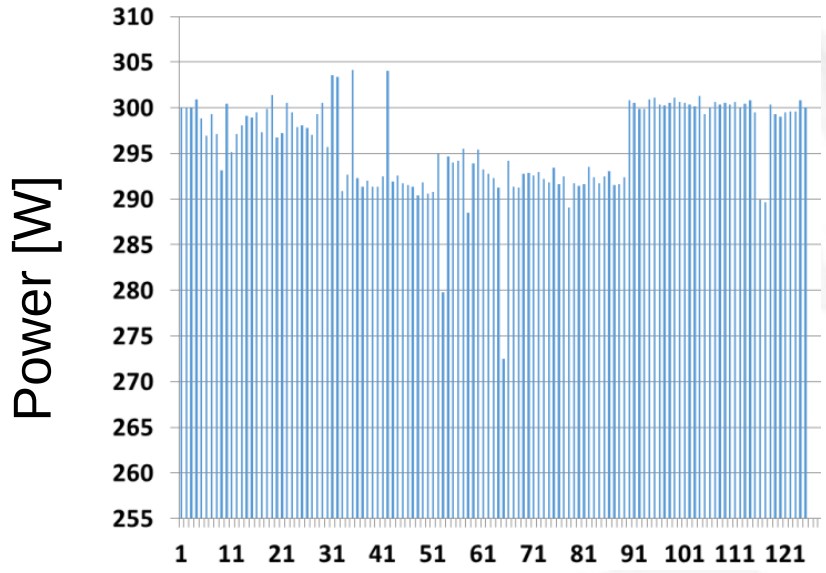
Managing Director
Dirk Fenske

Commercial Register Cologne
HRB 56171

8 hours test run at customers

160 MW Line installed in less than 2 months
600 modules produced 8h test after 2 months ramp up
24/7 production running today





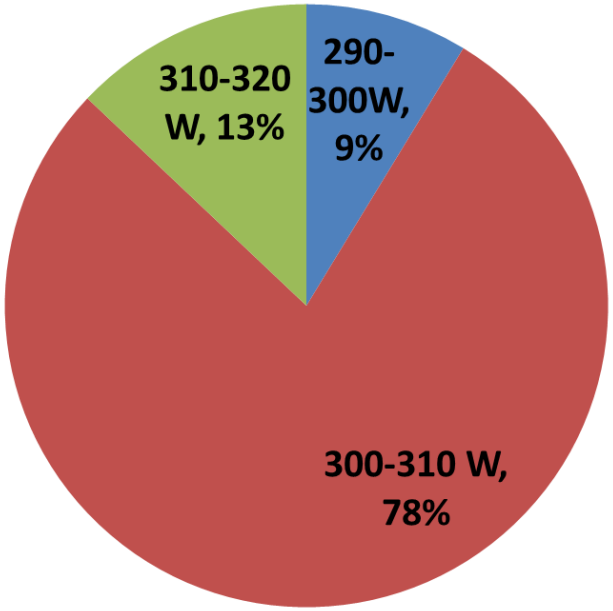
Courtesy T. Söderström, MBT

Module Line Performance

MEYER BURGER

Power distribution

1000 modules



	Pmax [W]	Voc [V]	Isc [A]	FF [%]
White Backsheet	**330.29**	**44.49**	**9.46**	**78.45%**
Black Backsheet	**320.42**	**44.42**	**9.07**	**79.52%**

5 / 34

TÜVRheinland®
Precisely Right.

Module type				Push Project 2016				
Test date [DD/MM/YYYY]				28/09/2016				
Irradiance [W/m²]				Corrected to 1000 W/m²				
Module temperature [°C]				Corrected to 25°C				
Remark:				Measurement with usage of a white backsheet foil				
No	TÜV barcode	P_{max} [W]	Dev. to P_{nom} [%]	V_{mpp} [V]	I_{mpp} [A]	V_{oc} [V]	I_{sc} [A]	FF [%]
1	HV2016003070	300.3	N/A	35.01	8.58	43.48	9.21	75.0
2	HV2016003071	310.9	N/A	36,17	8.60	44.16	9.23	76.3
3	HV2016003072	305.1	N/A	35.45	8.61	43.78	9.24	75.4

The measuring uncertainty of P_{max} is max ± 2.5 %
The measuring uncertainty of I_{sc} is max ± 2.3 %
The measuring uncertainty of V_{oc} is max ± 1.0 %
Measuring uncertainty includes spectral mismatch error.

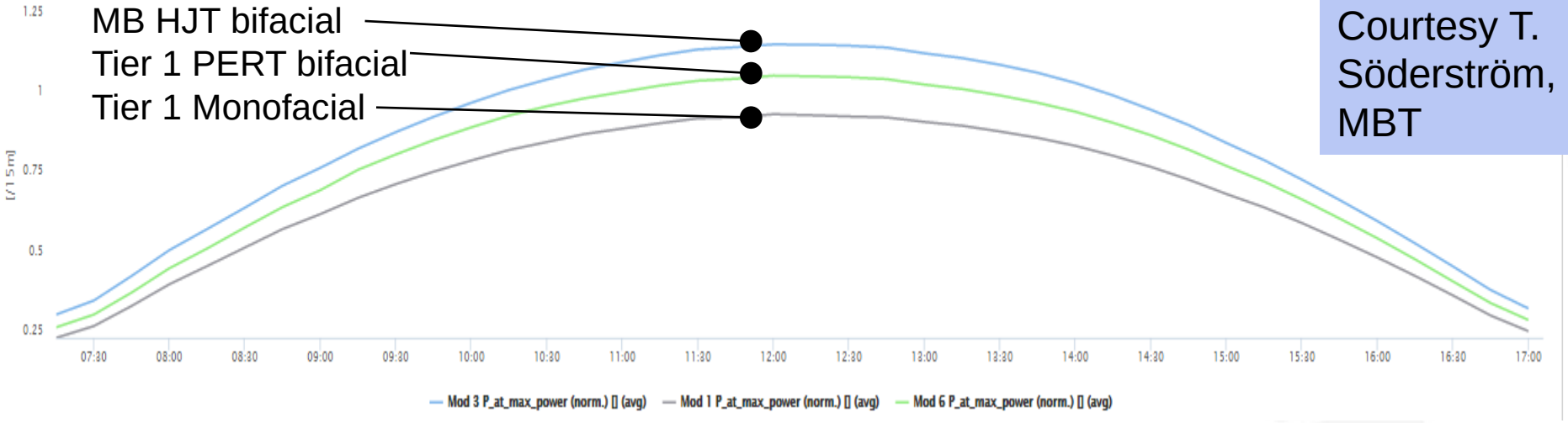
1000 module produced power between 300-320W measured with black backsheet

Monitoring in UAE

Measurement at real conditions

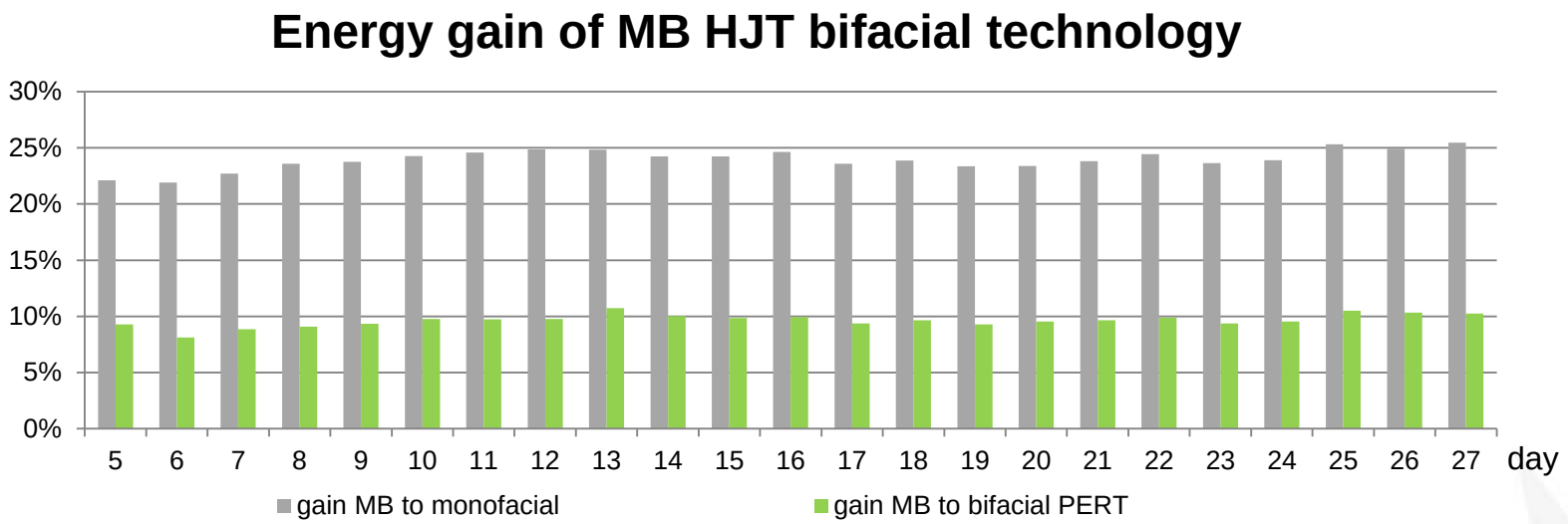
site with 8 modules bifacial and monofacial.

Example: 21st of April 2017, daily energy production



Courtesy T. Söderström, MBT

Gain of MB technology



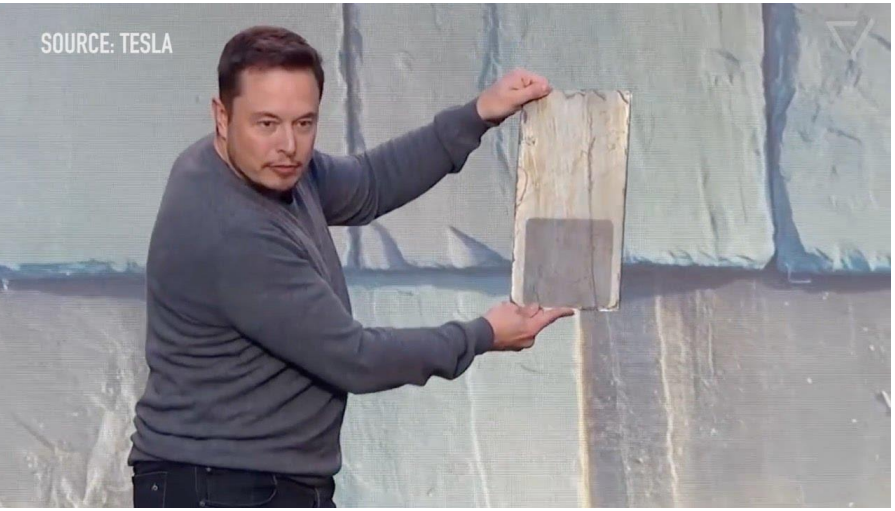
- MB modules have a gain of 20% to 25% compared to monofacial
- MB modules have a gain of 9% to 11% compared to bifacial PERT
- HJT technology showes the advantages: bifacial and low temperature coefficient

https://www.meyerburger.com/ch/de/messdaten-weltweit/

Courtesy T. Söderström, MBT


Solar Visualised in Europe Award 2016

ELEGANCE



Trend for BIPV

In Europe: many companies with small volumes

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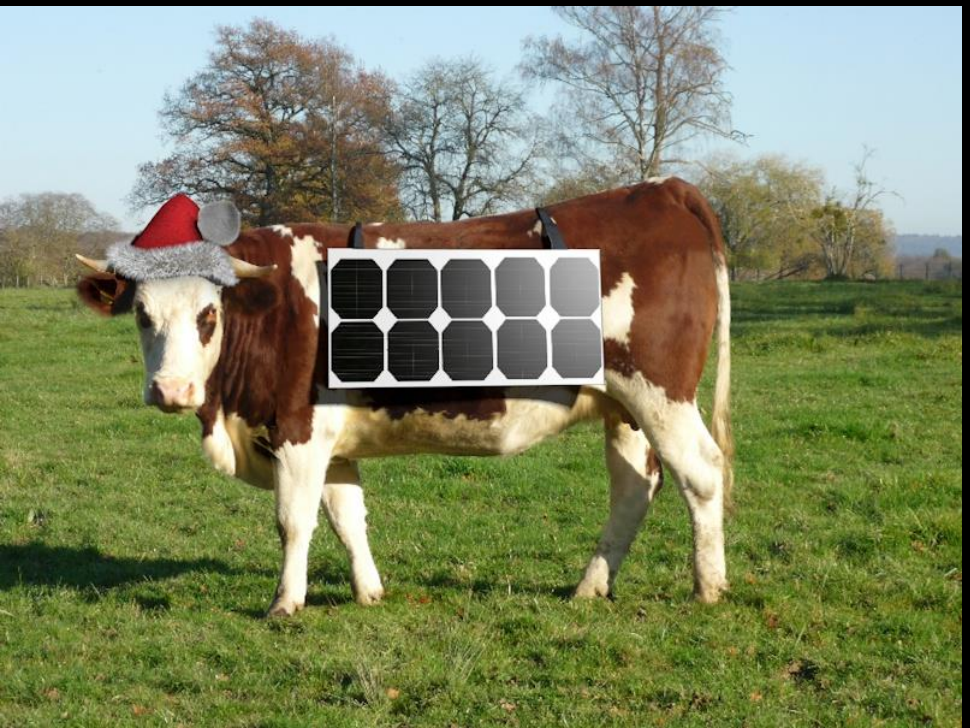
Switzerland, sensitive to acceptance in Rural and Urban Environment

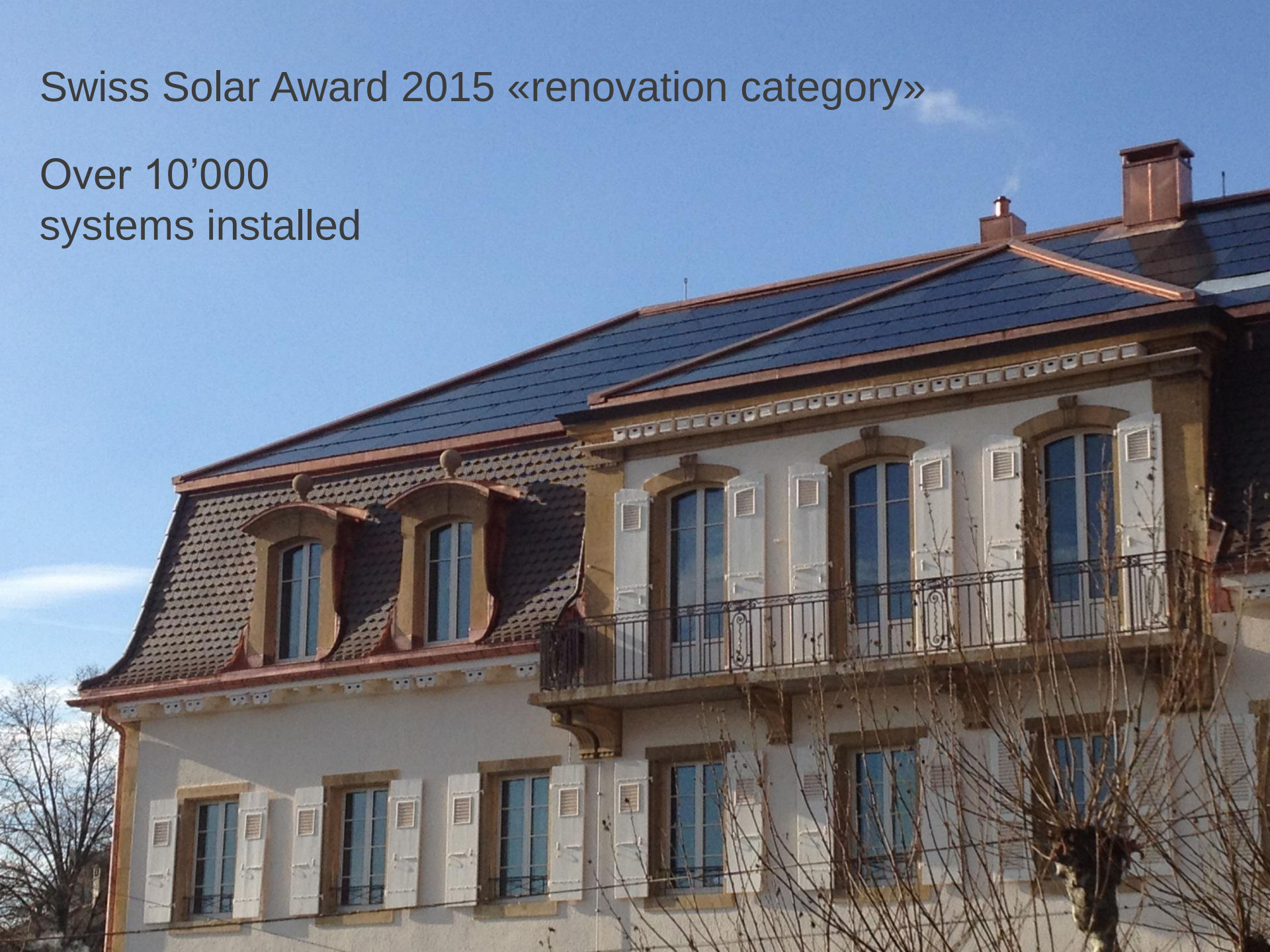
Sensitive to aesthetics



Integrated «Megaslates»

Swiss Solar Award 2015 «renovation category»

Over 10’000
systems installed



Panotron GASSER CERAMIC

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DESIGNERGY®

structurally integrated solar building solutions

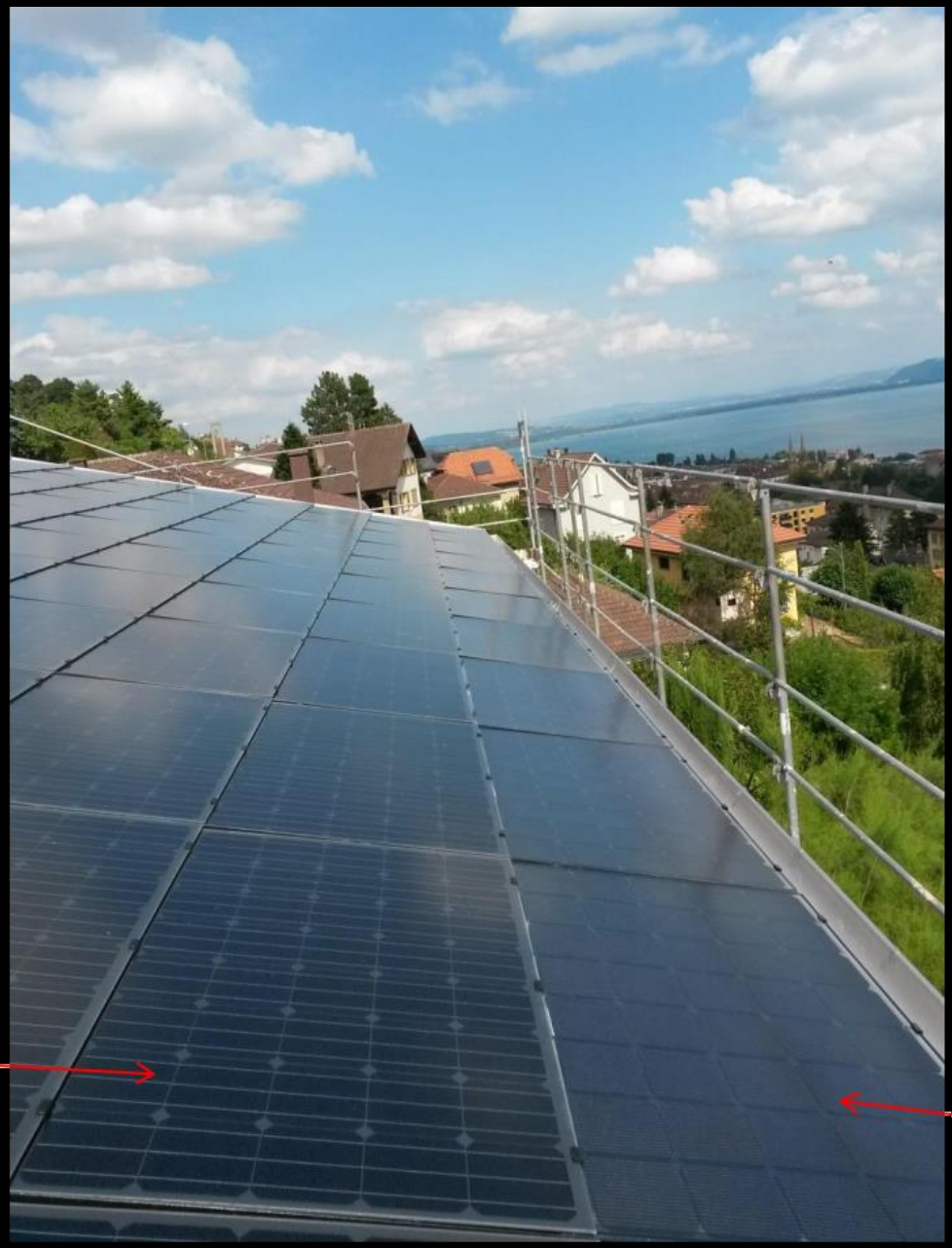
Aesthetics in PV

Thermal Insulation

H2O-tightness

Structurally tough

FIRST SMART-WIRE SHJ in roof «BIBV» megaslate configuration



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Terra-cotta PV

An example of technological transfer

Thin-film terra-cotta

Mat or shiny finish

Sizes: full size (1100 x 1400) and small size available

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Photovoltaic in buildings

Demonstration project in Switzerland

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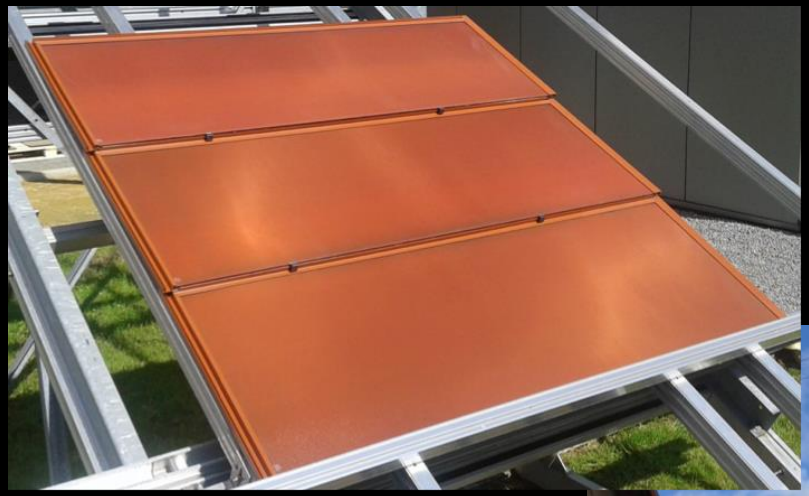
Change of strategy: crystalline c-si based terra-cotta module 115 w/m^2 together with Issol SA



Simulation, project under realisation

ISSOL

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White photovoltaic modules

A new building material

- Better aesthetics
- Easiest integration
- Building façade are becoming active
- Possible over 10% efficiency

➢ **A new building material**

Intensive Field testing

SOLAXESS
white solar technology

1st generation product with

ISSOL

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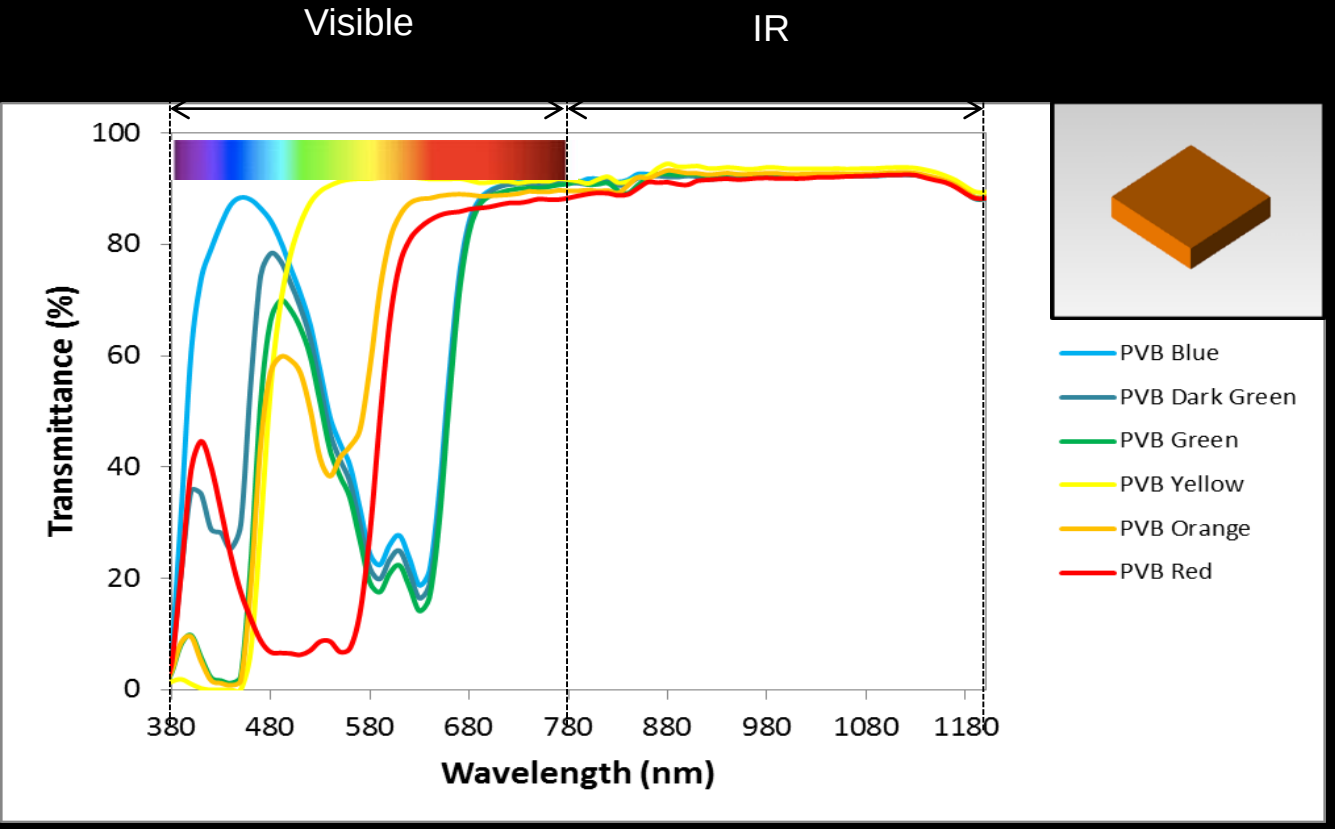
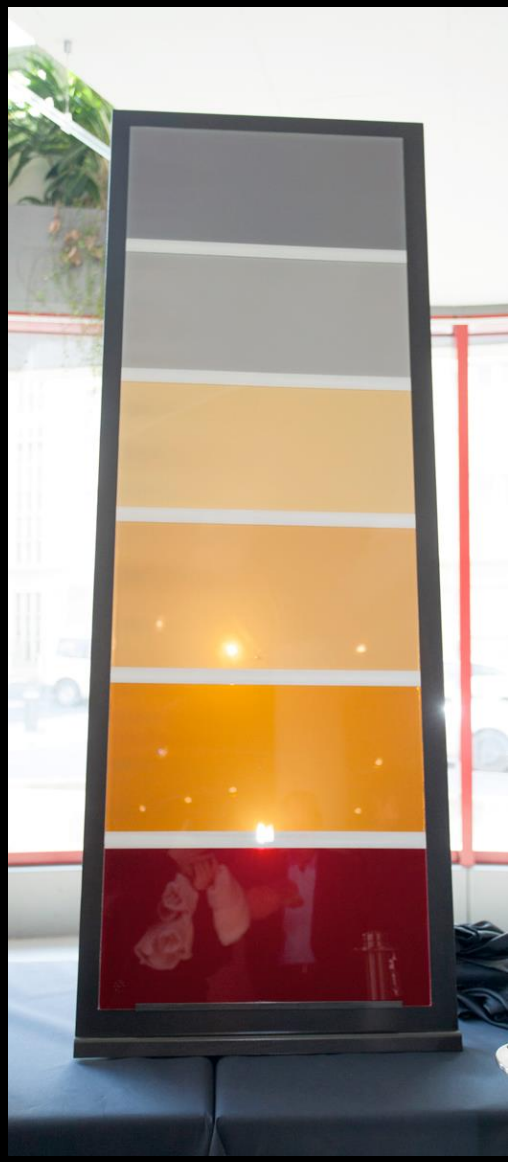
Colored photovoltaic modules

Next step





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Still a simulation


Still a simulation

Journal of Economic Geography **15** (2015) pp. 815–839
Advance Access Published on 7 October 2014
doi:10.1093/jeg/lbu036

Spatial patterns of solar photovoltaic system adoption: The influence of neighbors and the built environment[‡]

Marcello Graziano and Kenneth Gillingham**,†*

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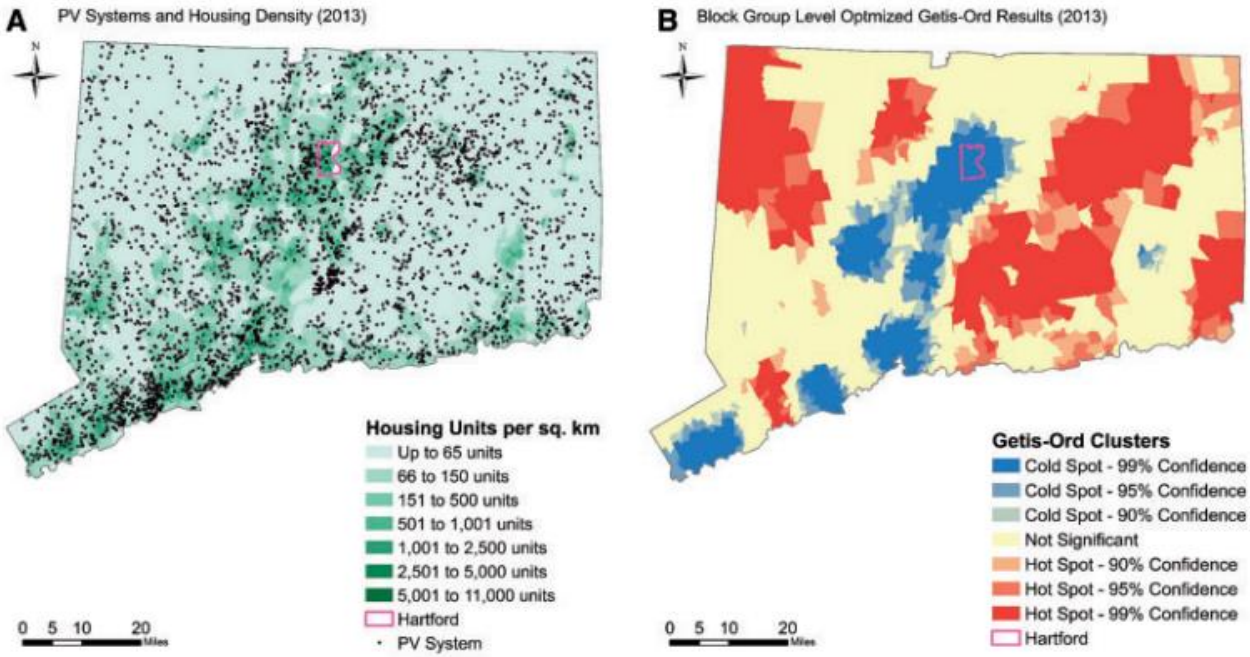
email <kenneth.gillingham@yale.edu>

Influence your neighboors ….

“Example isn't another way to teach, it is the only way to teach”, *A. Einstein*



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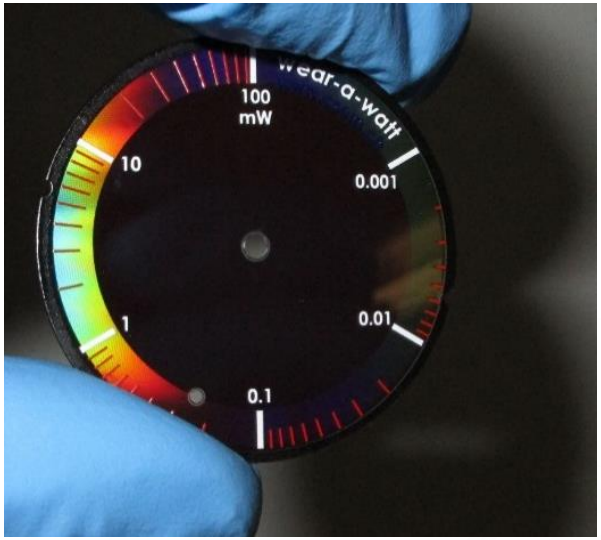
Connect



EXPLORE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EXPLORE

PV Modules Fabrication: Customized PV products

- Development of high-efficient integrated, light and robust PV element for solar plane and boat :
  - 700 g/m2 modules 21%, passing 200 cycles from -70°C – 85°C and 1000h in DH (85°C/85% RH)

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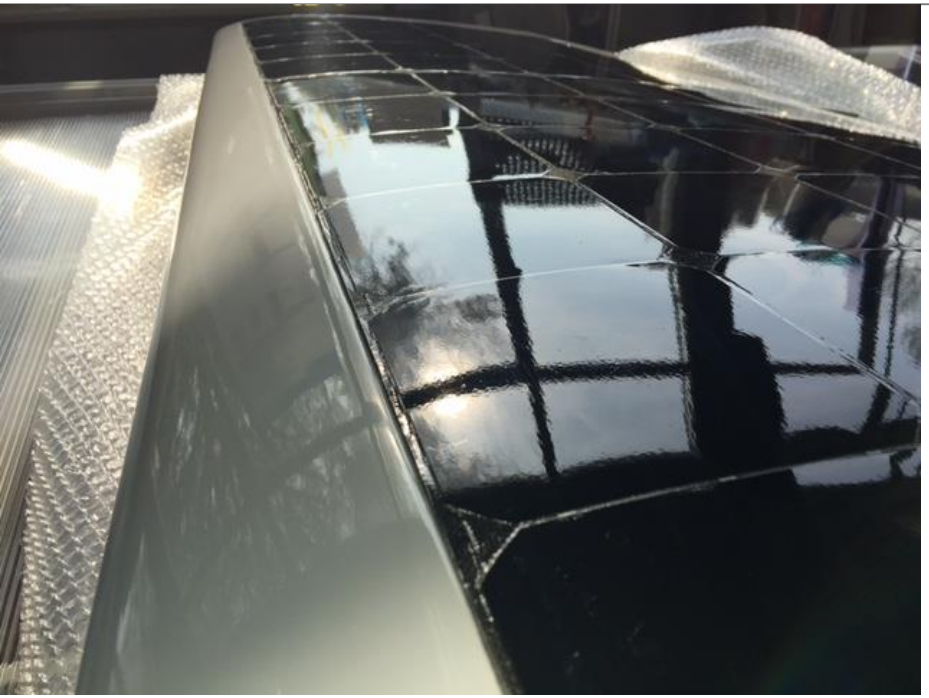

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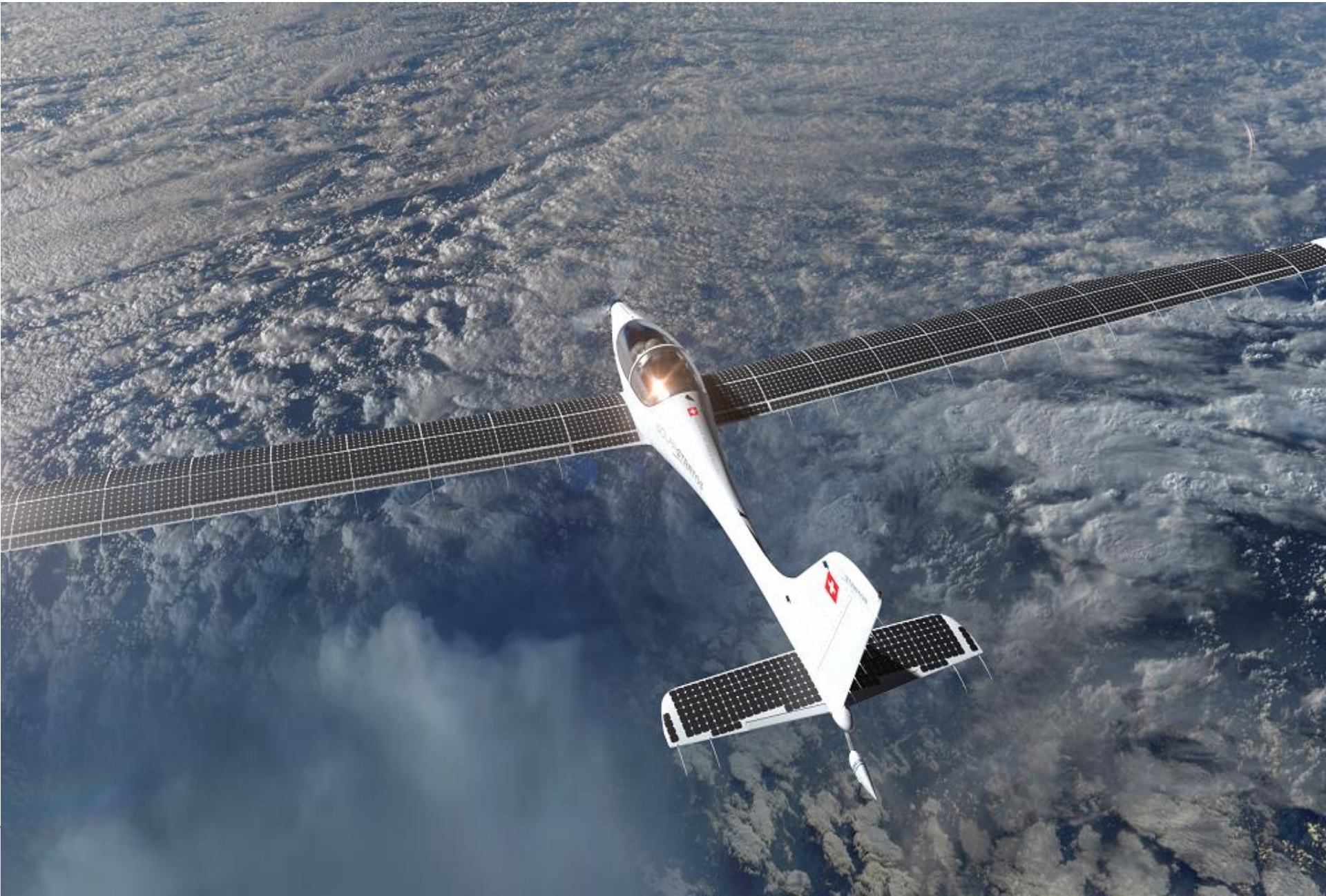
Solar Stratos… at the edge of space



Solar Stratos… at the edge of space

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Fährt mit Strom. Kein CO_2. Weniger Lärm.
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Fährt mit Strom.
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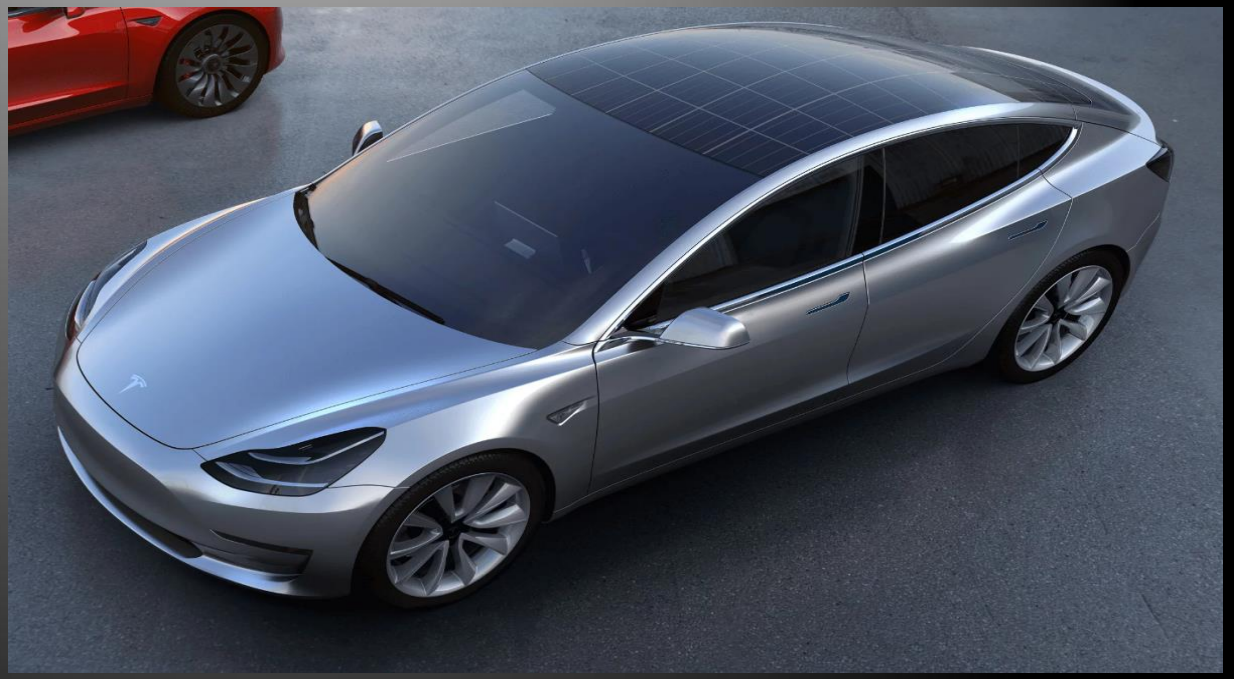

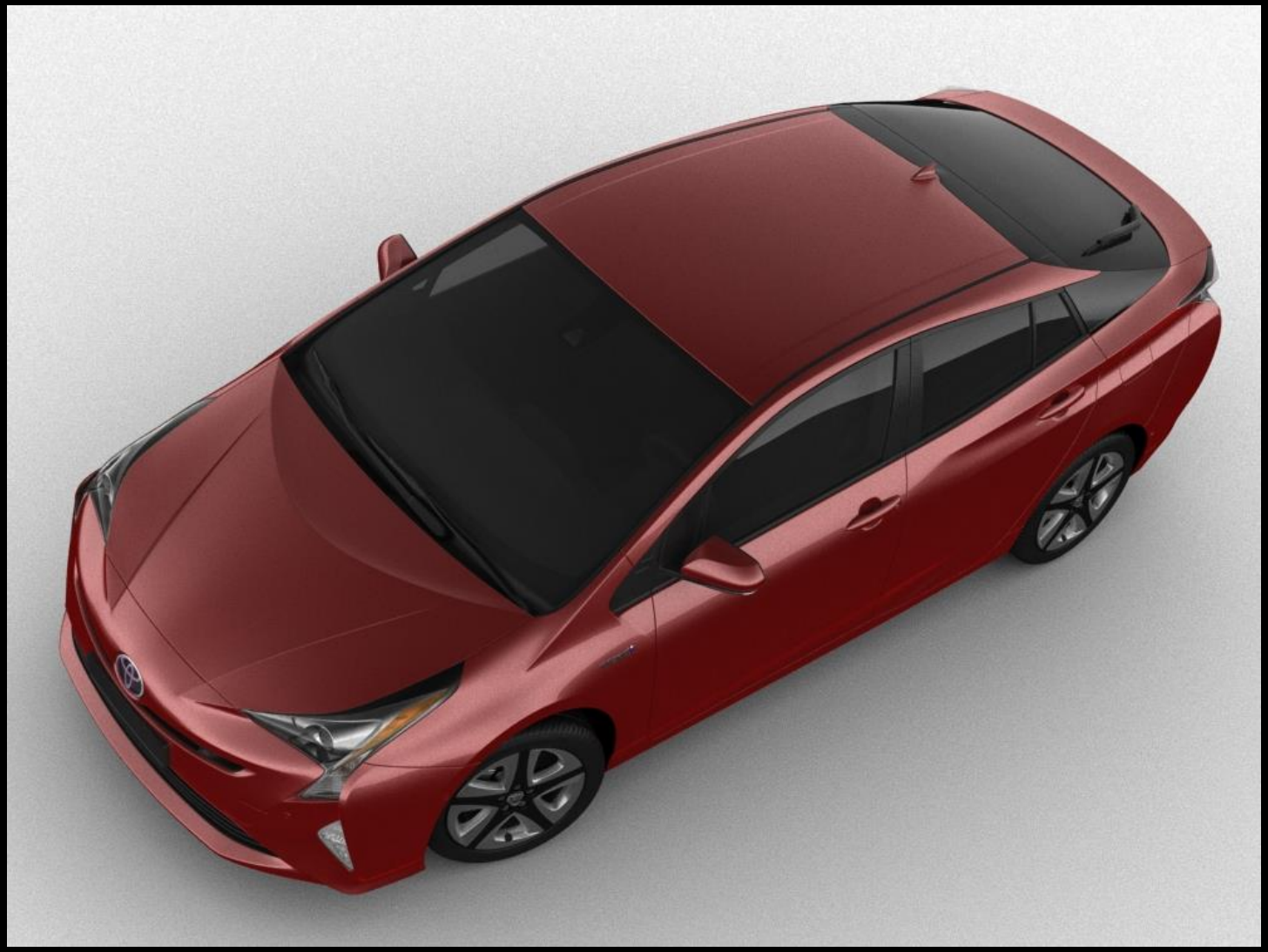

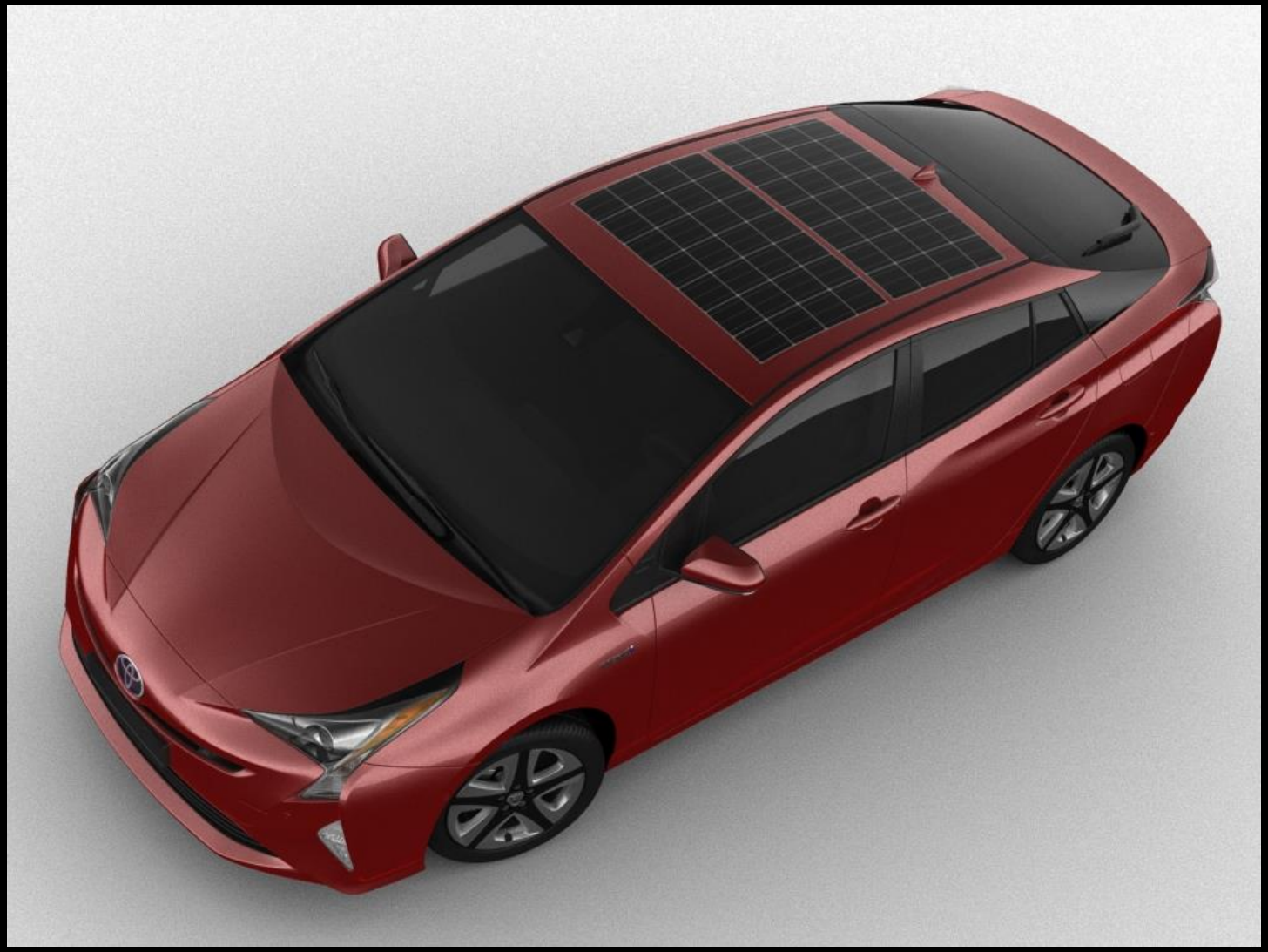

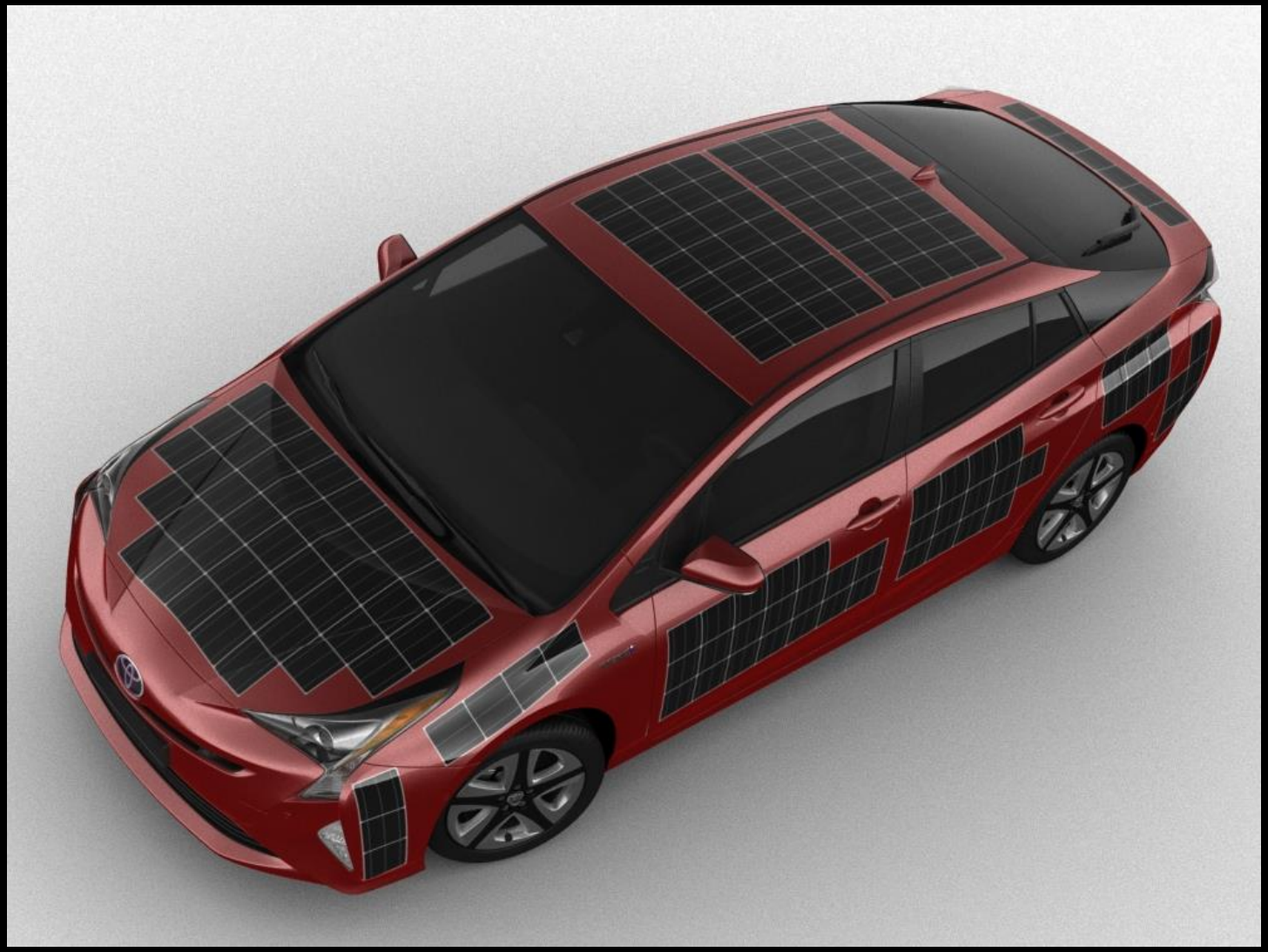

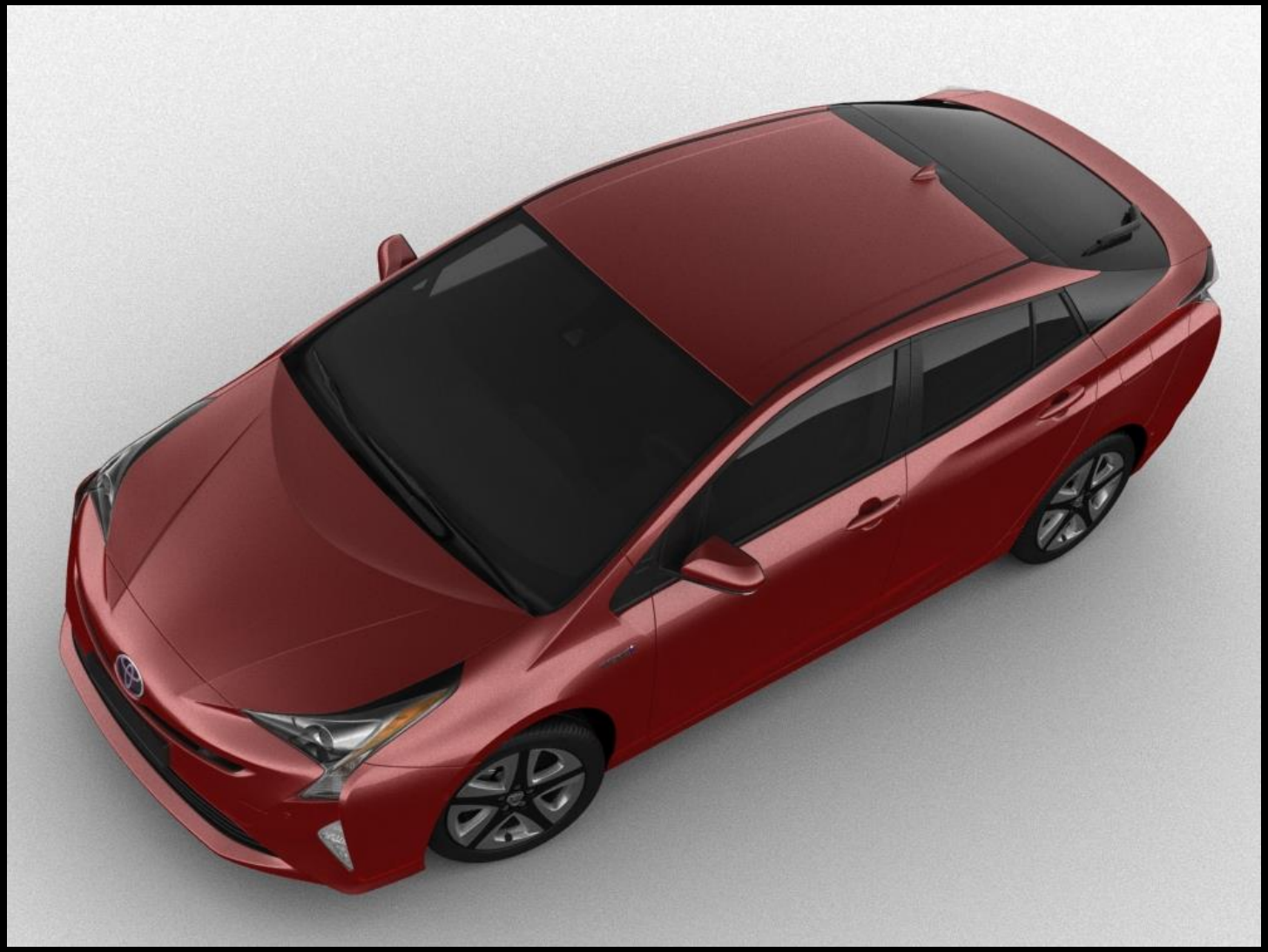

- To which extent can you color PV ?

The Kaleo Project ….

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Banque Cantonale Neuchâteloise


Banque Cantonale Neuchâteloise

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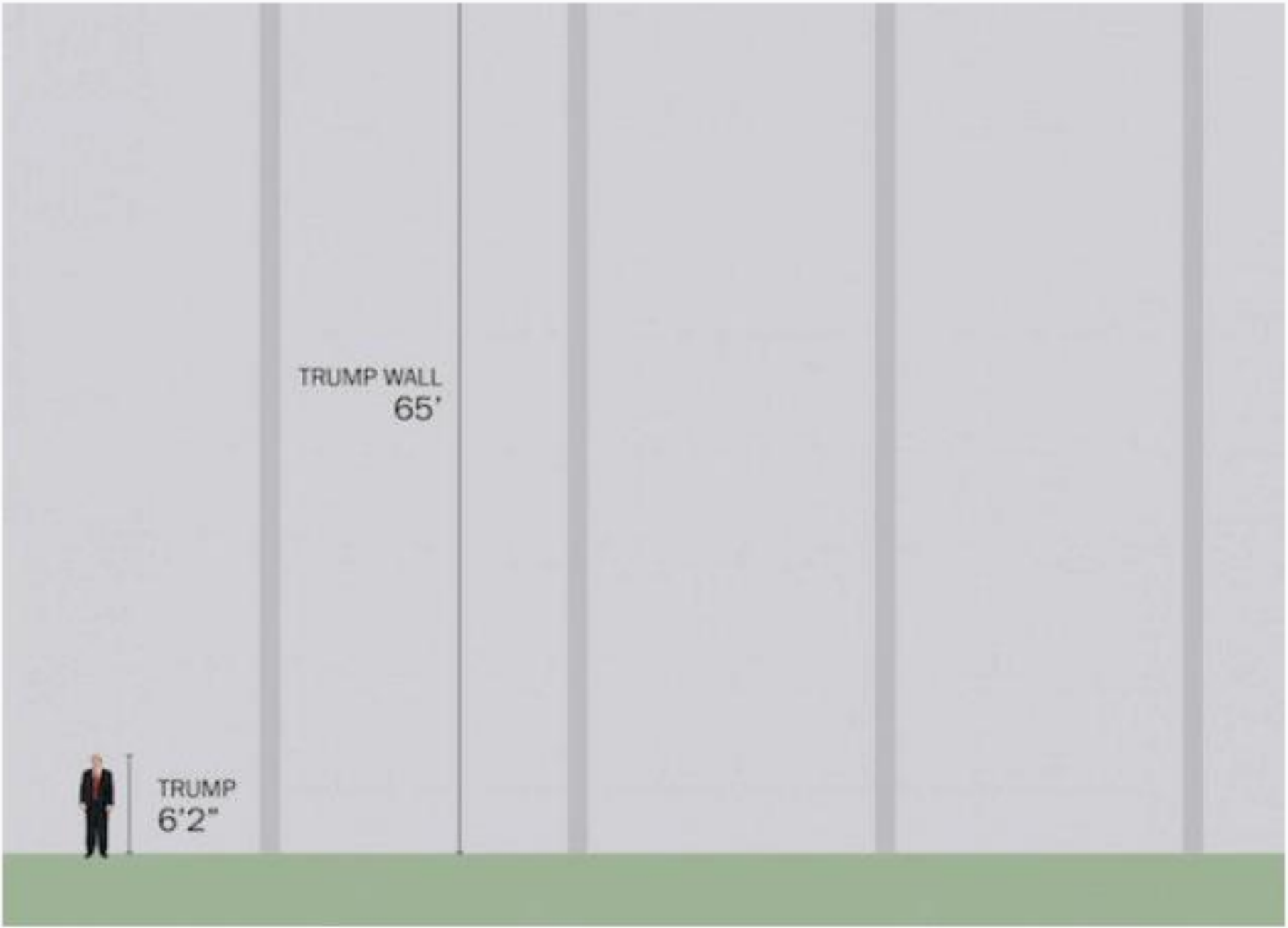

Source: Jigar Shah, LinkedIn

Source: Jigar Shah, LinkedIn

Solar electricity: a bright future with some more work ahead !

You may never know what results come of your actions, but if you do nothing, there will be no results.” *Mahatma Gandhi*

Thanks for your attention !

Solarstratos

THANK YOU FOR YOUR ATTENTION !!

BCN

SWISS INNO HJT

SunShot

PV2050

Schweizerische Eidgenossenschaft
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SEVENTH FRAMEWORK PROGRAMME

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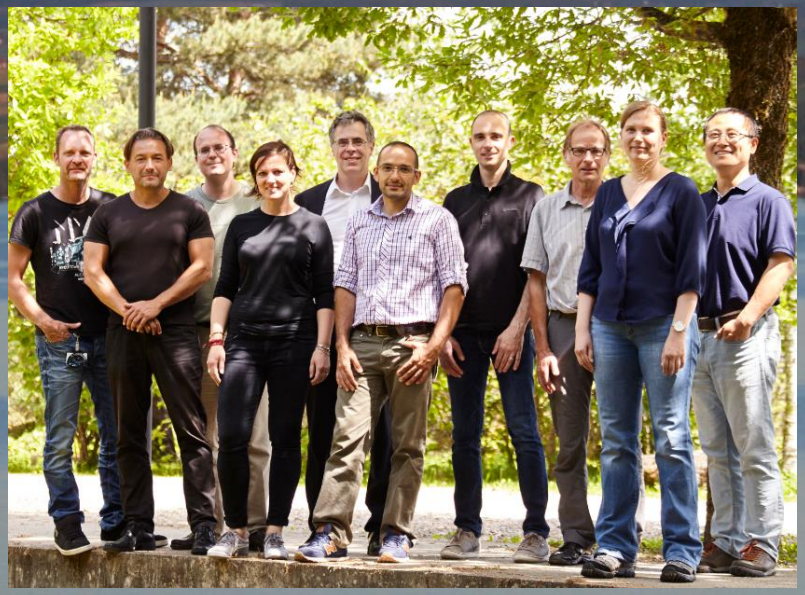
Thanks to EPFL and CSEM teams !

L.E. Perret-Aebi, P.J. Alet, J. Escarré, P. Heinstein, G. Cattaneo, K. Söderström, G. Bugnon, U. Furholz, P. Duvoisin, V. Chapuis, al. CSEM

M. Despeisse, A. Faes,, A. Descoeudres, C. Allebe , L. Barraud, B. Paviet-Salomon, J. Geissbuhler N. Badel,, F. Debrot, J. Champliaud, J. Levrat, J.Hoerzel, A. Lachowicz, P. Groninger

Nicolay, J. Bailat, Didier Dominé, L. Löfgreen, G. Christman, D. Sachetto, L. Sansonnens, P. Gröniger, S. J. Moon, J.W Schuttauf
et al. at CSEM

M. Boccard, J. Haschke, S. De Wolf, S. Essig, A. Tomasi, J. Seif, J. Cattin, S. Nicola, et al. At EPFLS. B. Niesen, J. Werner, A. Walter, M. Morales, Ph. Löper, F. J, Haug, N. Wyrsch, A. Hessler, Q. Jeangros G. Nogay, J. Stueckelberg, P. Wyss et al… A. Virtuani, E. Annigoni , A. Martins, at EPFL
C. Bucher, J. Fonjallaz, R. Tscharner, and technical team at EPFL and CSEM
B. Strahm, D. Lachenal, P. Papet, D. Baetzner et al., MEYER BURGER RESEARCH, Neuchatel
T. Söderström, Y. Yao, J. Zhao , E. Vetter, S. Leu et al. MEYER BURGER, CH-DE,
Shojei, F. Jeanneret, et al. Indeotec SA, I. Sinnico et al. Oerlikon/TEL solar
J. Bullock, A. Cuevas, et al. Berkeley and Anu, S. Essig et al, NREL, M. Topic et al. ULubjana



Kaleo team. L. E. Perret-Aebi et al

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