

# Swiss PV conference 2017

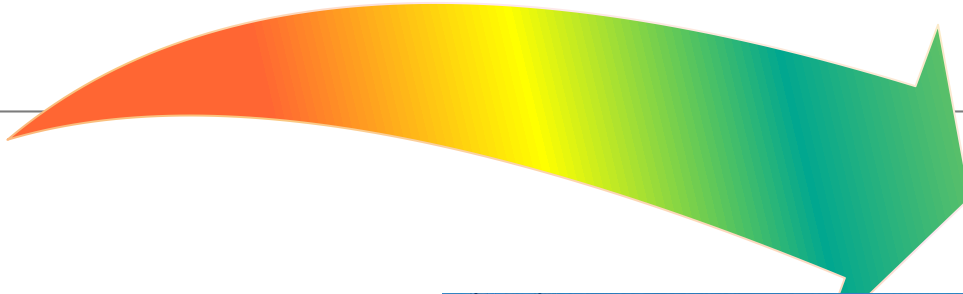
## Photovoltaïque et gestion de l'énergie : un aperçu des activités au CSEM PV-center

Prof. Christophe Ballif  
[christophe.ballif@csem.ch](mailto:christophe.ballif@csem.ch)

<sup>2</sup>Centre Suisse d'Electronique et Microtechnique (CSEM), PV-Center  
NeuchatelEcole Polytechnique Fédérale de Lausanne (EPFL) , Photovoltaics and Thin-Film  
Electronics Laboratory, PV-lab



# R&D in photovoltaics in Neuchâtel



ÉCOLE POLYTECHNIQUE  
FÉDÉRALE DE LAUSANNE



IMT NEUCHATEL

**EPFL**

IMT/PV-Lab (1984)

- Fundamental research
- Advanced devices



**csem PV-Center**

**CSEM, RTO**

PV-Center (since 2013)

- Focus on techn. transfer
- Dev. for industry, innovation

Production and  
commercialization



Industrial partners  
Spin-off, Start-ups

In contracts with  
over 40 companies

# Application fields

**Powerpure**  
technologies for lowest cost  
solar electricity

2020 >20%, < 0.4€/Wp, > 30 years  
2026 >23% <0.3€/Wp, > 40 years  
high energy yield

Talk by  
L.E.  
Perret-  
Aebi

**Elegance and architecture**  
transforming building and cities  
with solar

All shapes, all colors, and/or active  
construction material

**Smart**  
intelligent E-management,  
efficiency in building,  
storage, renewable

Algorithms and electronics/  
IT services  
managing light, heat, electricity

**Explore**  
customized PV  
products from the  
water to the air

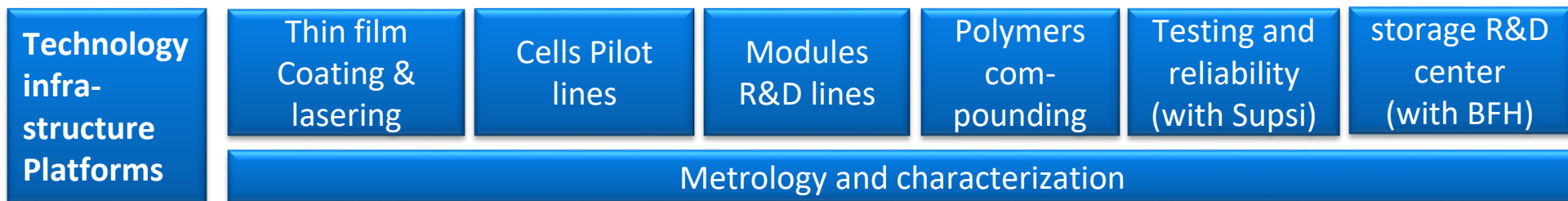
Lightweight modules and power  
solutions for planes, drones, cars  
and more

**E-tonomy**  
energy scavengers  
and ubiquitous  
power sources

20% indoor  
autonomous  
harvesters,  
connected

# Key infrastructures

from coatings, to cells with polymers, to  
modules, to systems



Over 2000 m sq of lab and facilities in Neuchatel  
(and Fribourg and Basel CSEM MuttENZ)



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





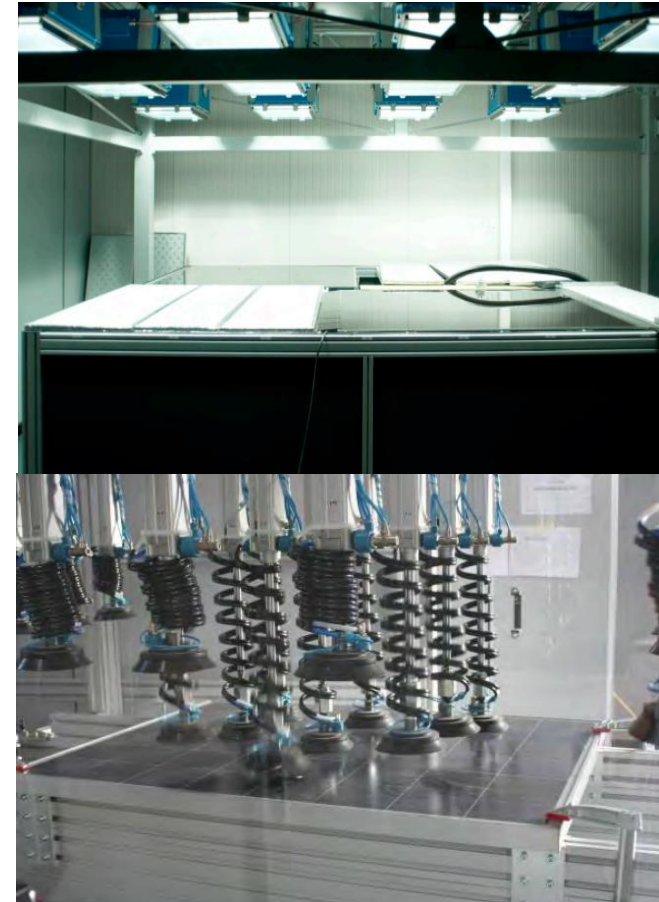
# SUPSI-CSEM cooperation on modules and PV systems

**SUPSI**

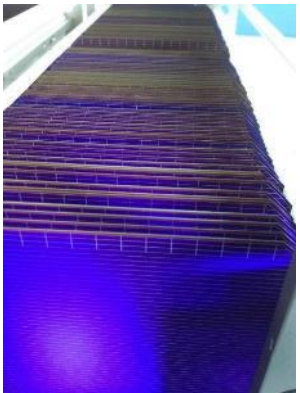
Scuola Universitaria Professionale  
della Svizzera Italiana

- Objectives
  - Development of novel PV products
  - Advanced reliability testing, wide range of tests
  - Failure modes, predictive performance and maintenance of PV power plants
  - Support to a broader range of national and international companies

**CSEM offers performance measurement curve on Neuchâtel site, validated by Supsi !**

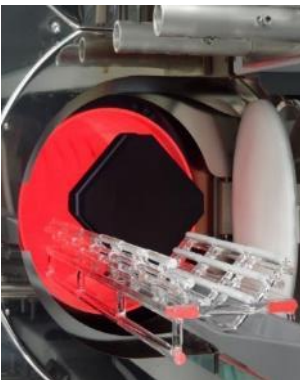


# POWERPURE



Low temperature  
Heterojunction  
solar cells

Lowest cost  
At highest efficiency

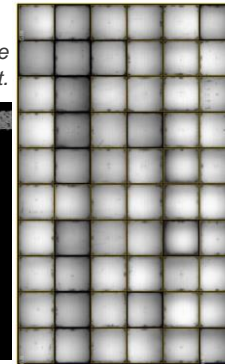
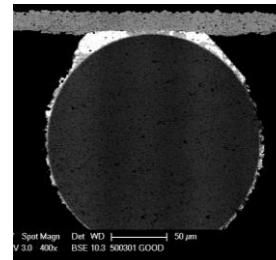


High temperature  
passivating contacts

Extending standard  
technology

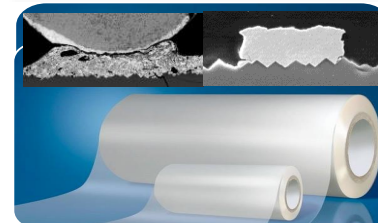
Metalisation and multi-wire  
interconnection for crystalline silicon

*Indium free coating for wire  
interconnect.*



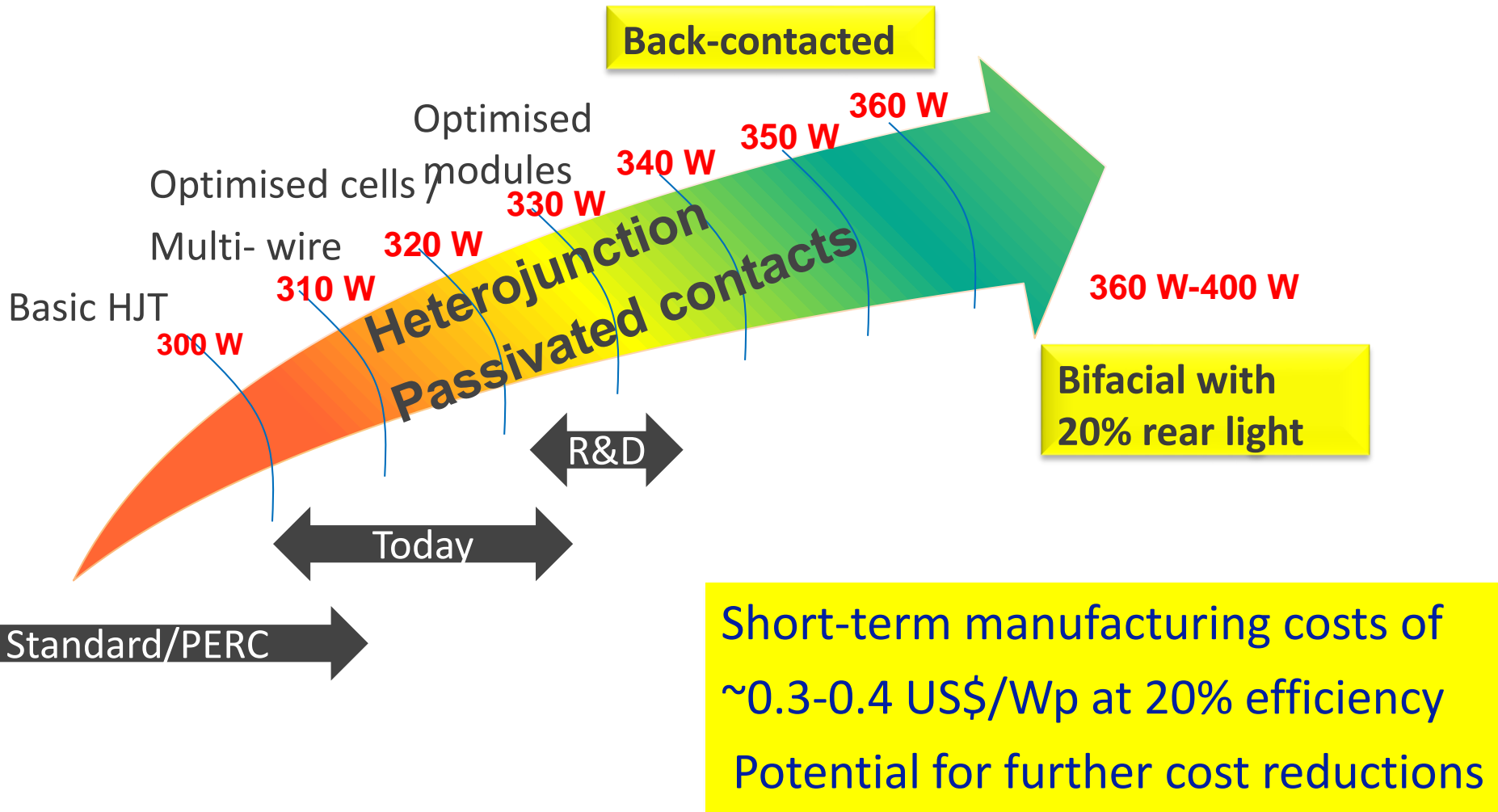
Optimal  
Module  
structures

Polymer design, extrusion and  
reliability of PV components



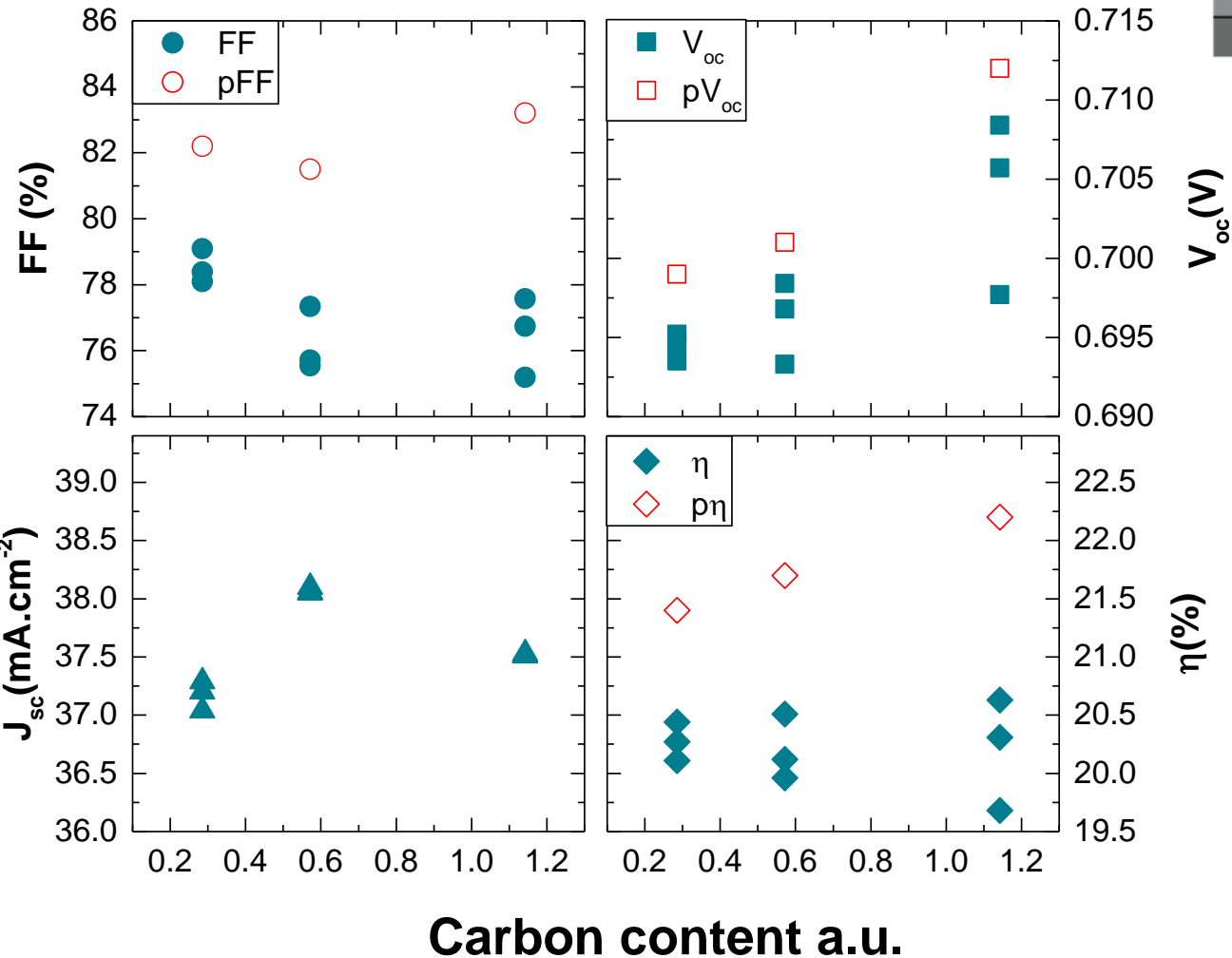
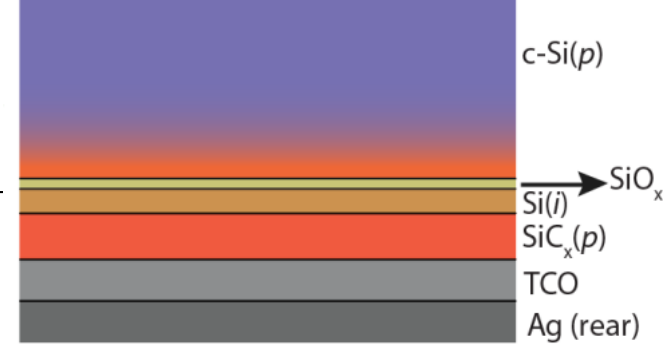
Ultimate  
reliability

# Future of c-Si SHJ modules, 60 cells, 6''





# Diffused rear contact «stable» at 900°C

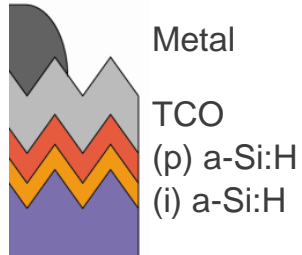


*G. Nogay et al.*  
*A. Ingenito et al*

**V<sub>oc</sub> value of >>  
 700 mV on p  
 type wafer  
 reached**

# SCREEN-PRINTED SILICON HETEROJUNCTION SOLAR CELL

Hole-selective passivating contact

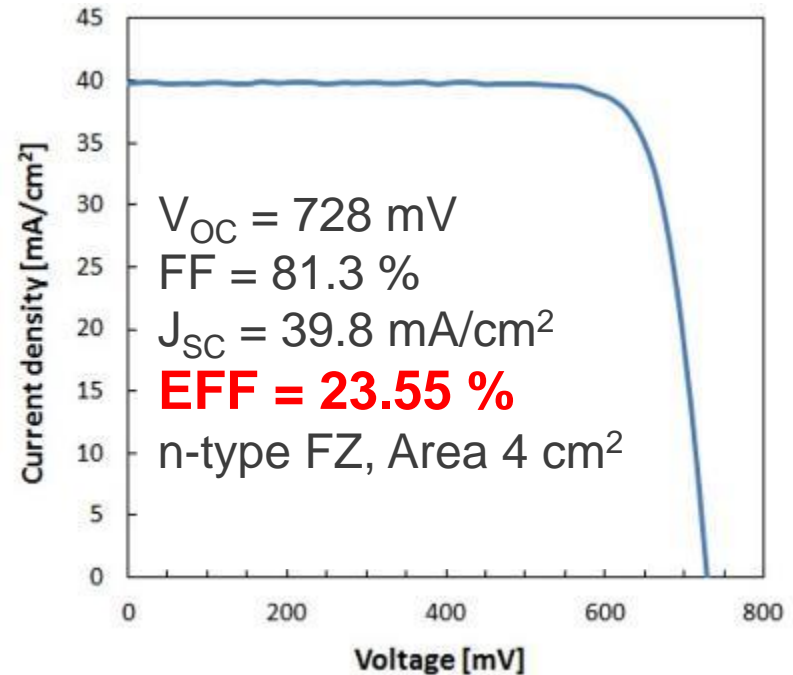
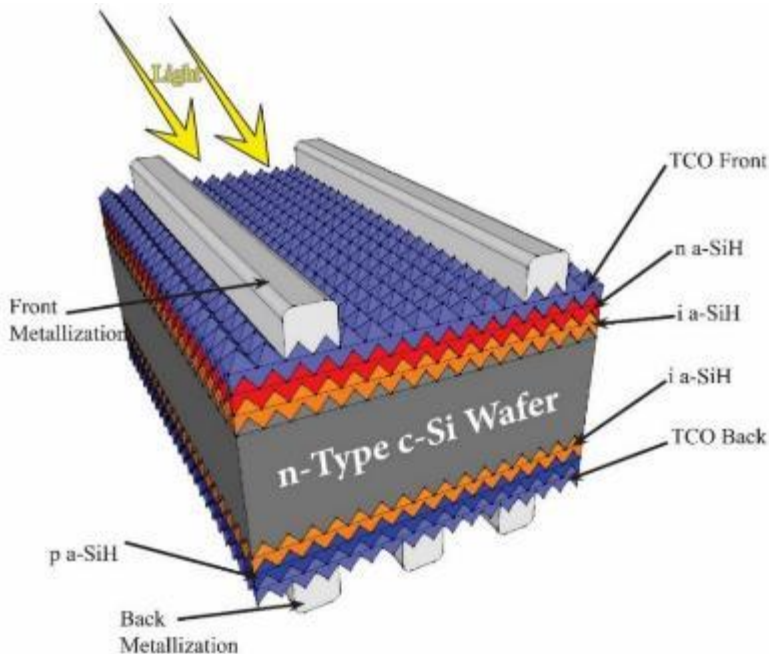


(i) a-Si:H of hole selective heterocontact key for performance

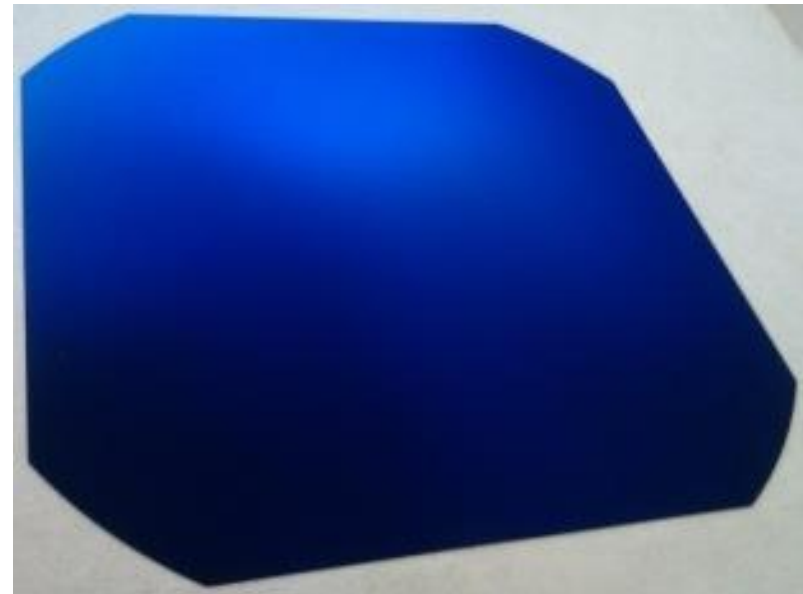
New thin (i) a-Si:H layer:



ENABLES high FF (up to 81.7 % achieved in front emitter).  
 Example EFFICIENCY @ **23.55 %** (ITO & screen printing)



## C-Si Heterojunctions with all contacts at the back



- Simplest process (Patented) to make back-contacted devices

Efficiency > 23% achieved

*A. Tomasi, B. Paviet Salomon et al, Nature Energy, to be published*



# Multi-wire high performance/reliability: SmartWire Contacting

**329 W GG  
60-cell module\***

**Module bifaciality  
factor: 92.4%**

\* Measured at SUPSI  
with a white backsheet  
taped to the module



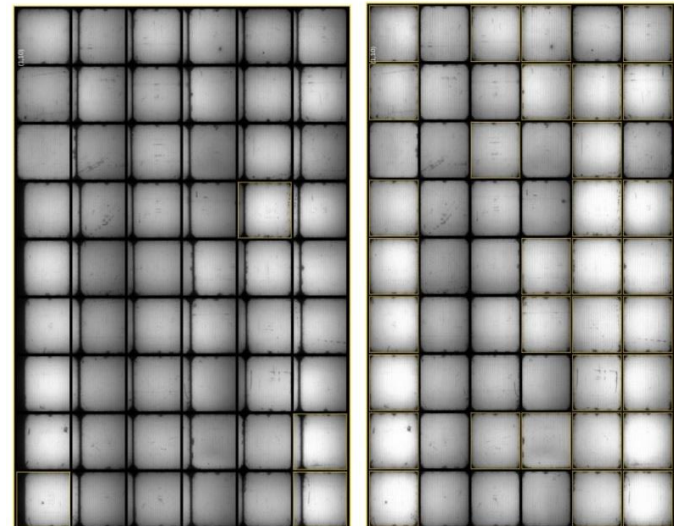
**All wafers  
and cells made  
at MB**



**MEYER BURGER**

High Reliability demonstrated  
< 5 % degradation

after TC 800 and DH 4000 h  
TC 0 TC 800



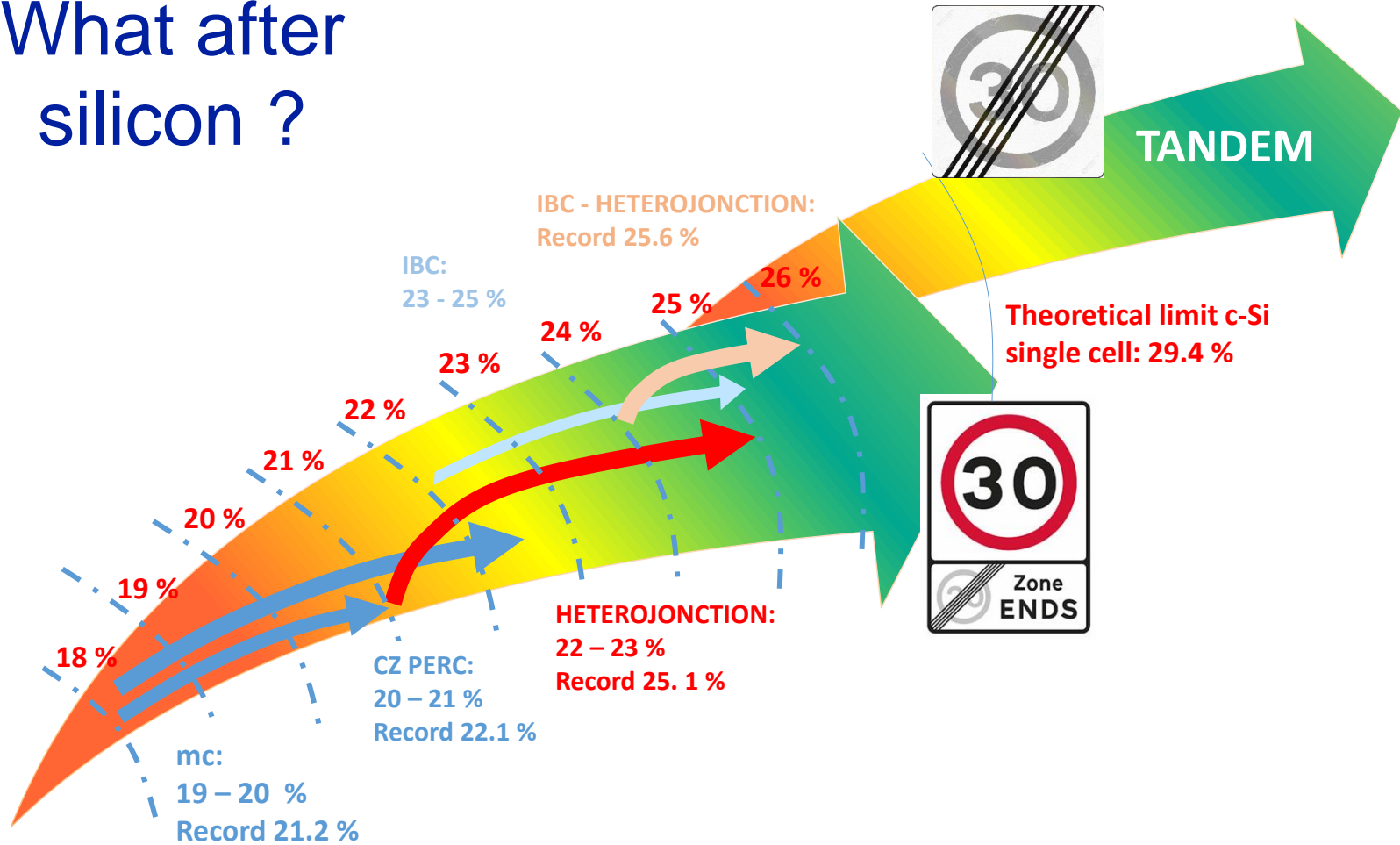


**Example: CSEM bi-facial, «smart-wire»  
Heterojunction facade, with 22% cells**





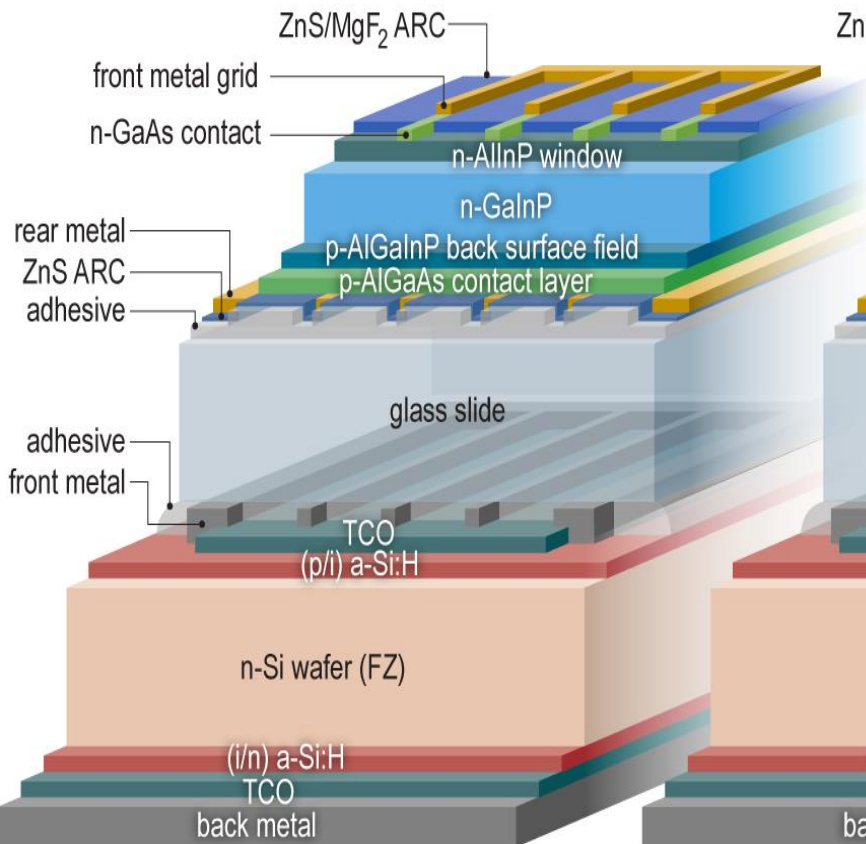
# What after silicon ?



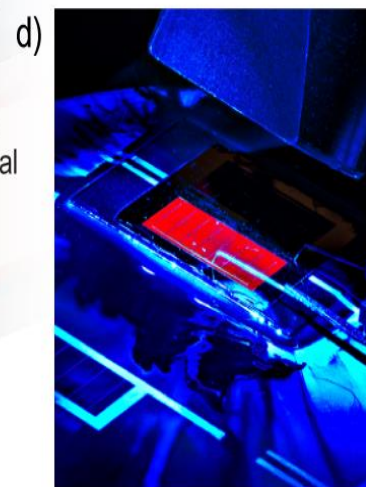
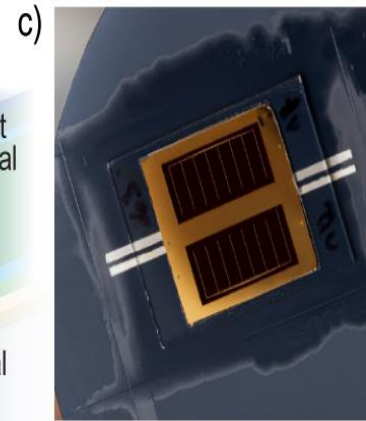
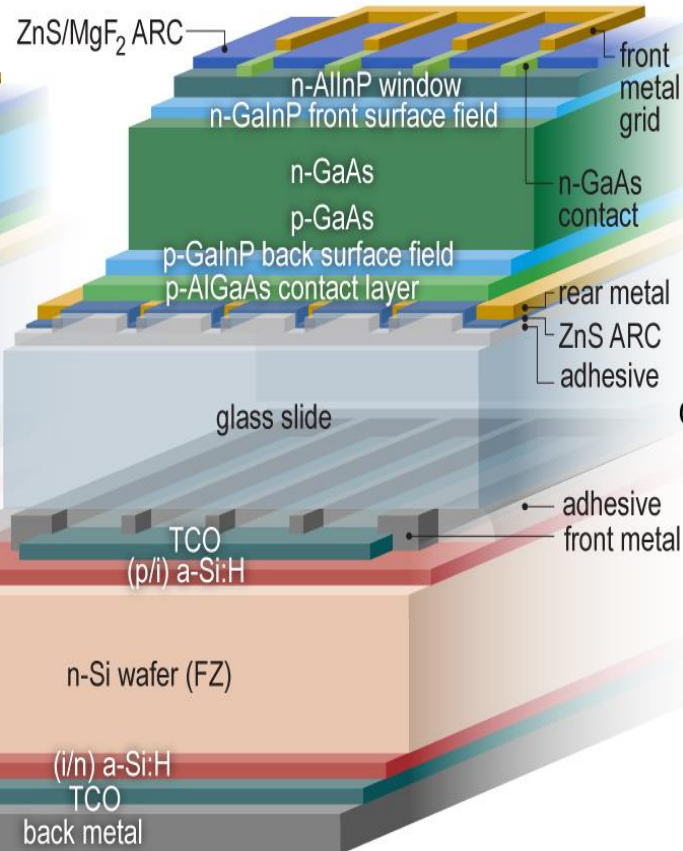


# Mechanically stacked III-V//Si tandem solar cells

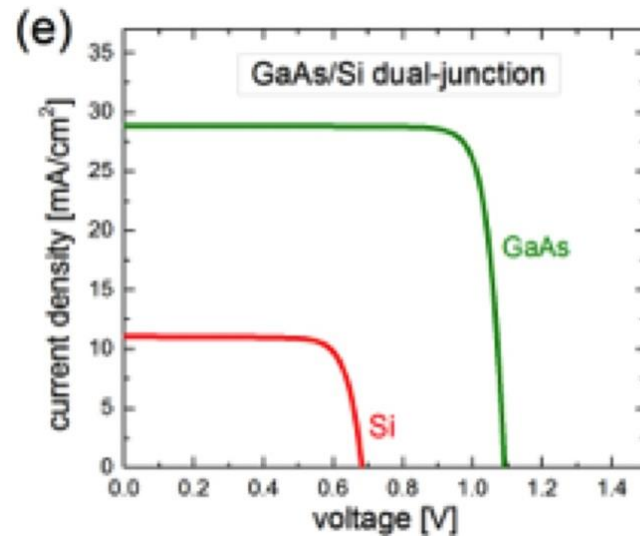
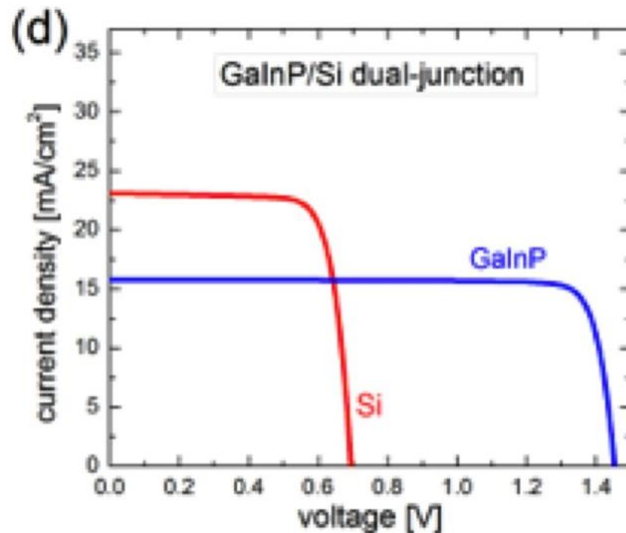
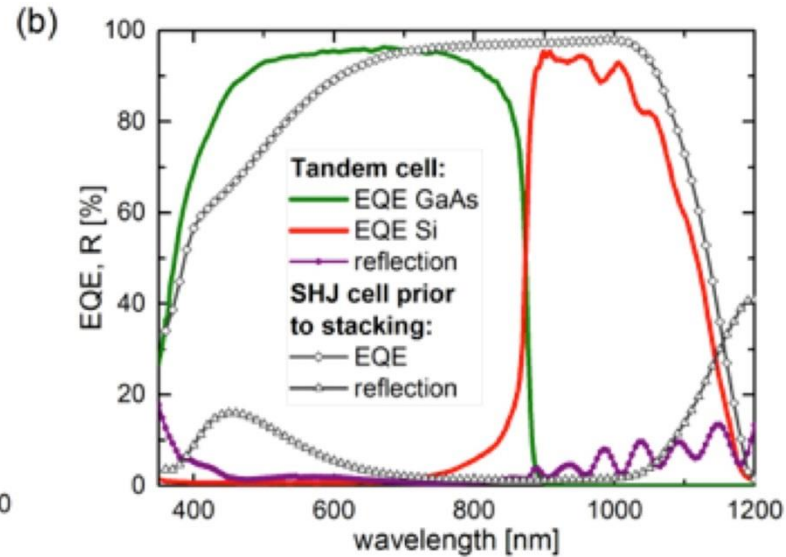
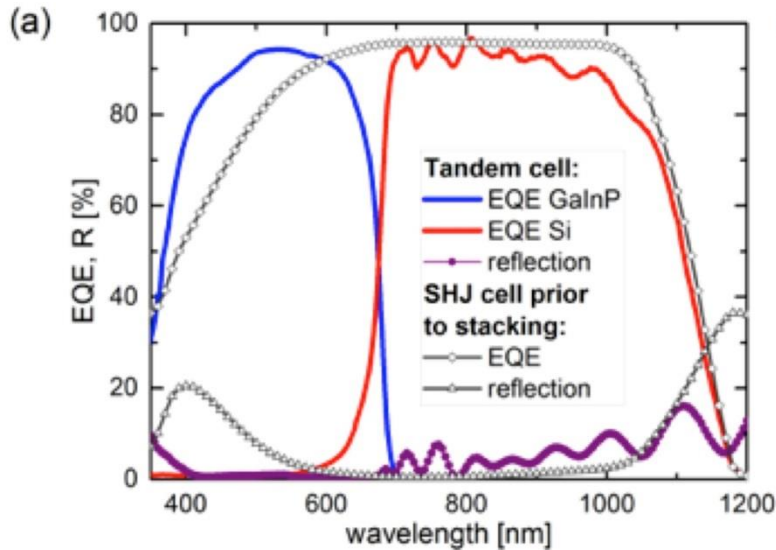
a) GaInP/Si Tandem Solar Cell



b) GaAs/Si Tandem Solar Cell



# Mechanically stacked III-V // Silicon Tandem: record results



**GaInP/Si**  
**> 32%**

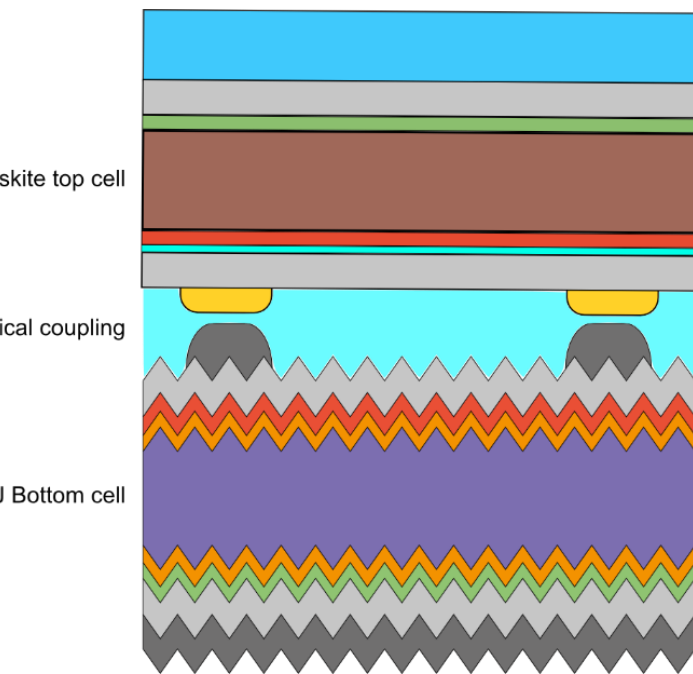
**GaAs/Si**  
**> 32%**

S. Essig et al. IEEE  
 JPV 2016  
 S. Essig et al.  
 Submitted

# Record «low cost potential» next generation devices

«Potential low cost»  
Perovskites on Silicon, 4  
terminal measurements

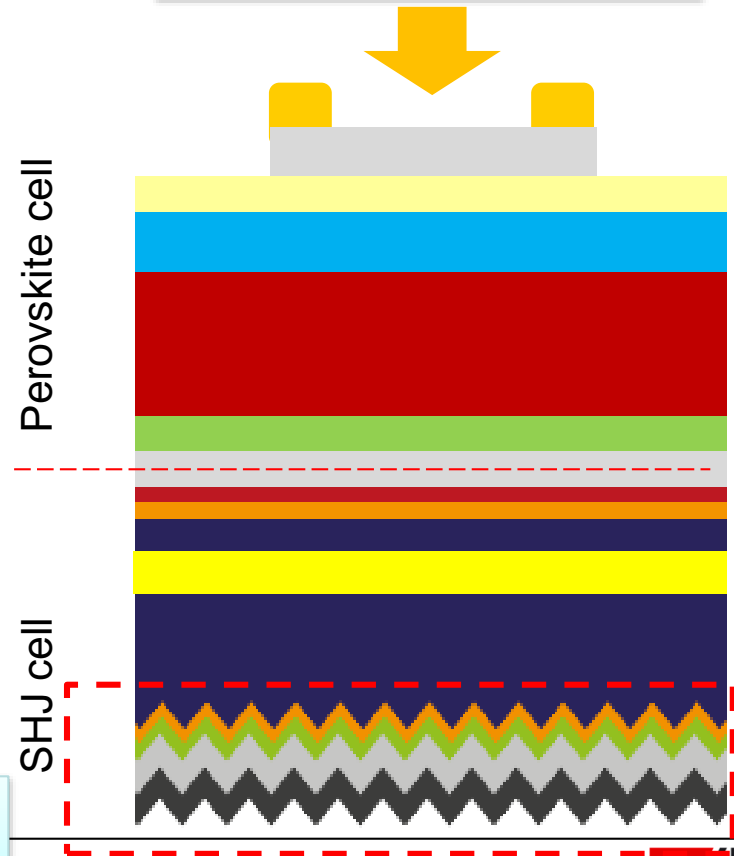
25.6% in house



J. Werner et al. JCS  
F. Sahli, unpublished

Full integration into 2  
terminal devices

> 22% in house





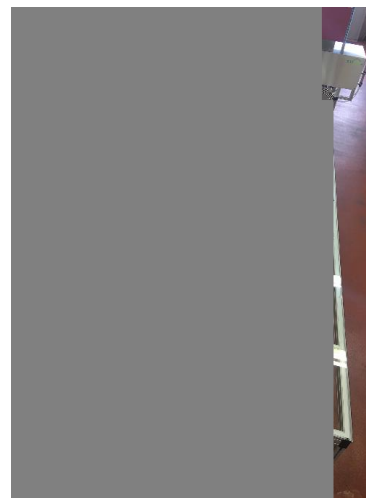
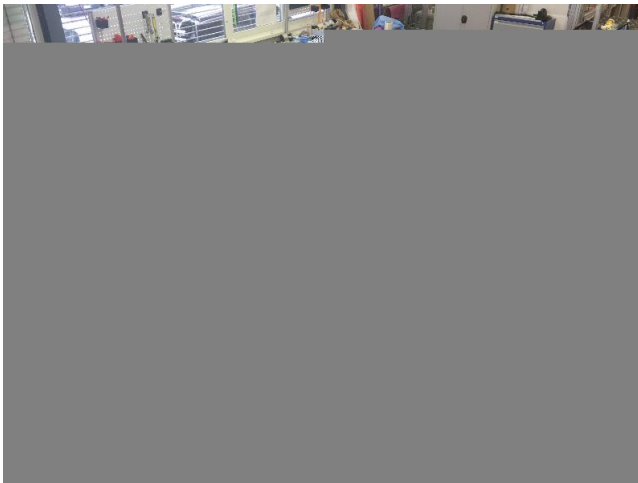
# EXPLORE



# Tools for specialty PV products



Formulation, compounding, extrusion, diffusion layer



Special tool for assembly light weight moduels

Exemple:

< 700 g/m<sup>2</sup> modules  
21%, passing 200 cycles  
from -70°C – 85°C and  
1000h in DH ( 85°C/85%  
RH)

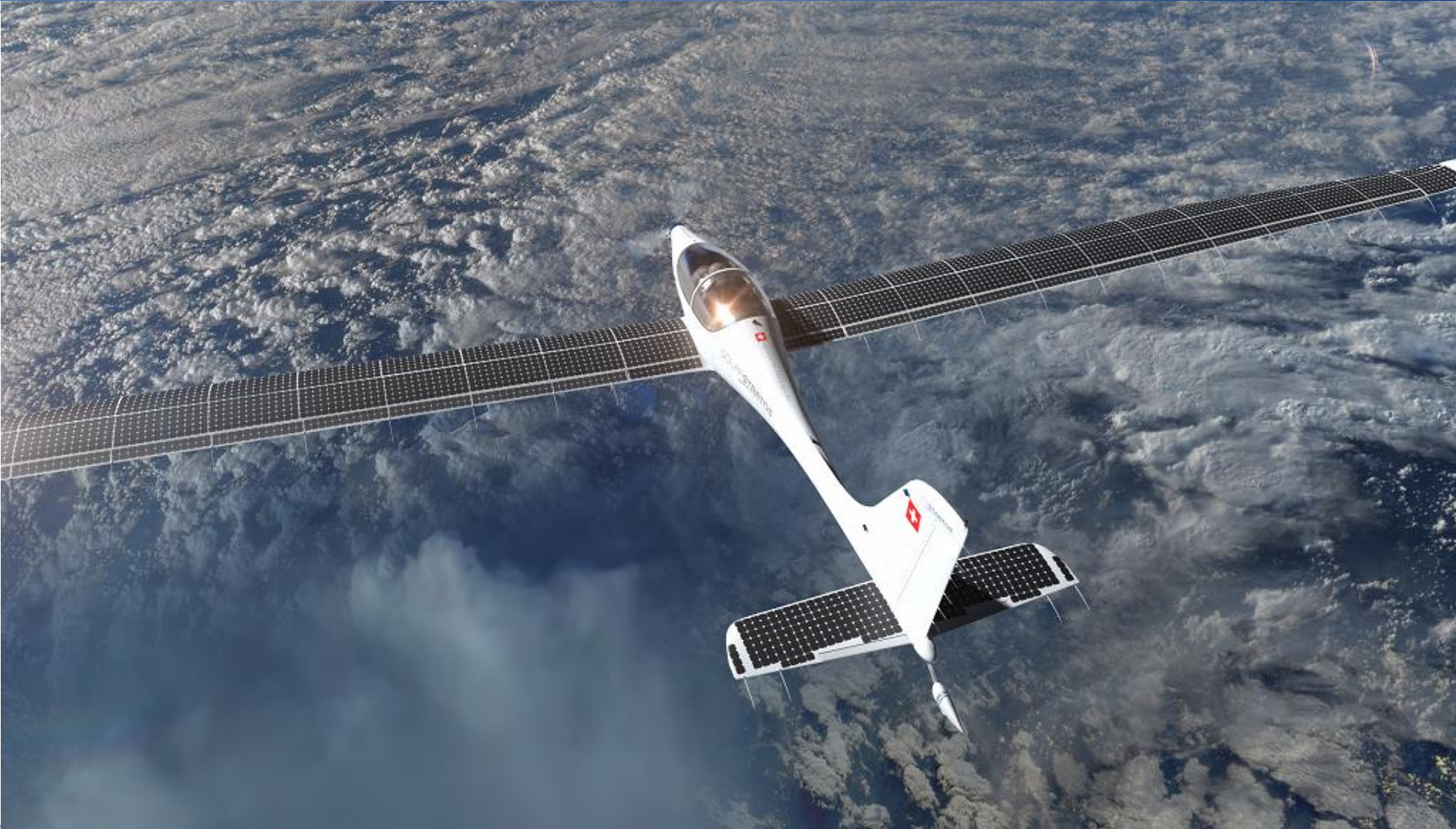


# EXPLORE





# Solar Stratos... à la frontière de l'espace





# Smart: Energy management

# Smart: Energy management

## Collaboration with Berner Fachhochschule: **BFH-CSEM Energy Storage Research Center** Research on batteries and supercapacitors



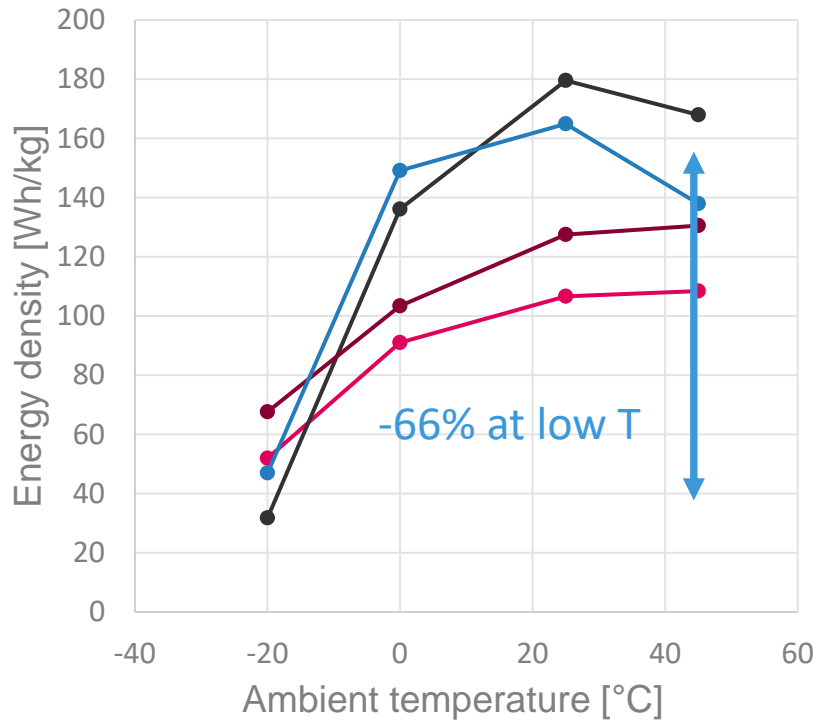
### Objectives:

- Assessment of potential and impact of grid-tied electrochemical storage
- **Predictive modelling**
- **Development of system solutions based on PV-tied storage**



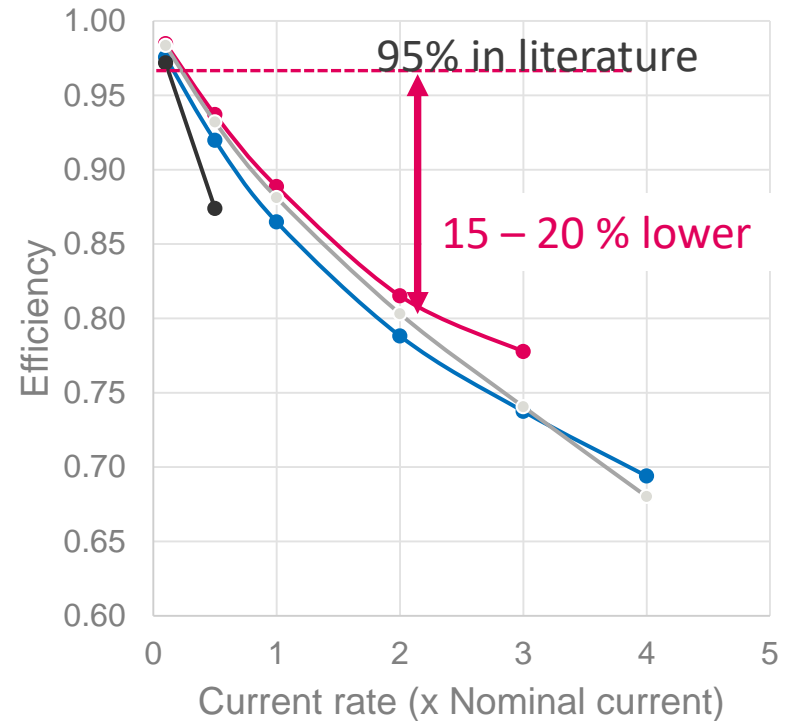
# Battery dependence on operating conditions

Lithium energy density



- Cylindric LiFePO4
- Pouch LiFePO4
- Prismatic LiCoO2
- Li-polymer

Lithium NMC efficiency



- 0% - 100% SoC
- 50%, ±5% SoC
- 20%, ±5% SoC
- 0%, ±5% SoC

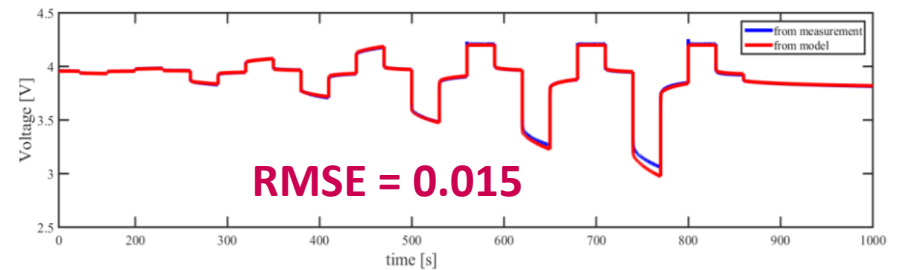
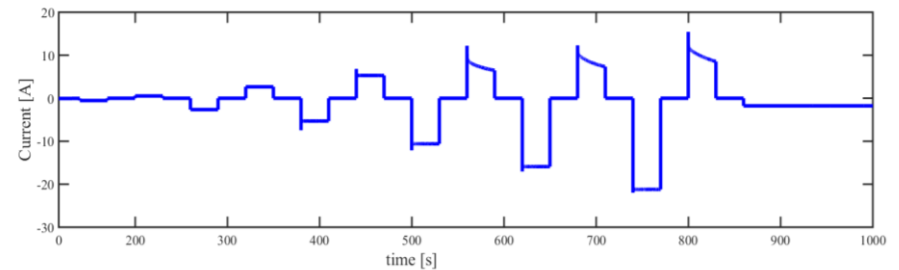
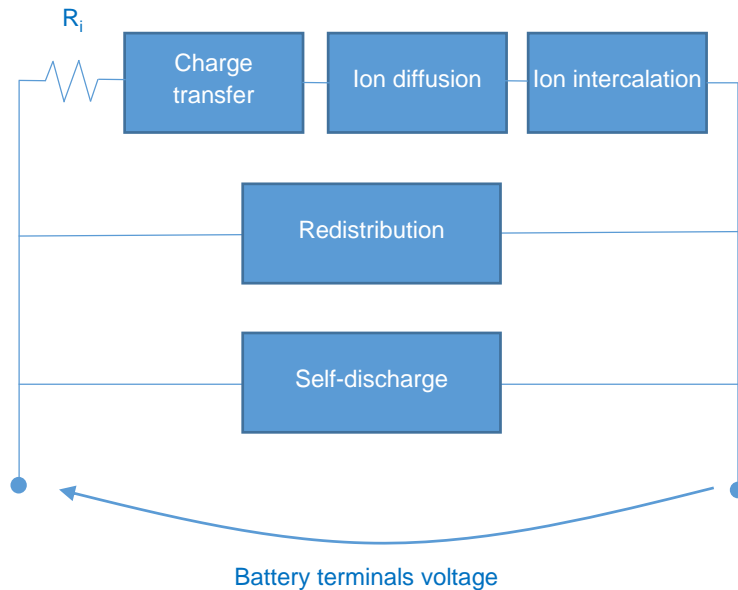




# Physical battery performance model

**Objective:** model incl. electrical, thermal, aging characteristics

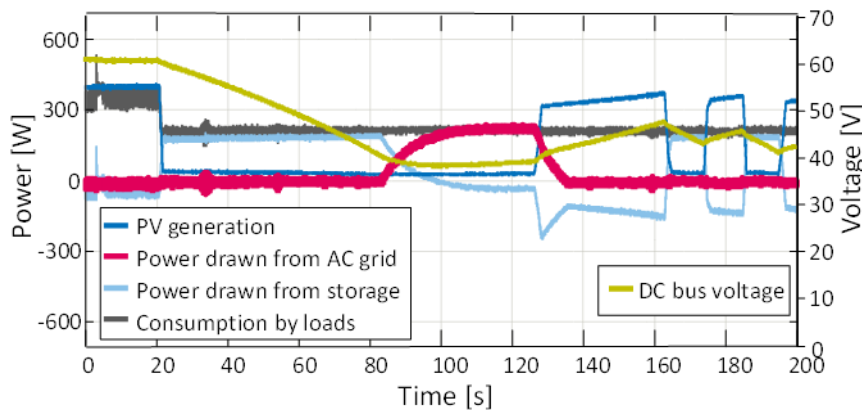
## Electrical model



application to **system design**, e.g. simplified model for system integrators

# Integration examples

LVDC microgrid demonstrator

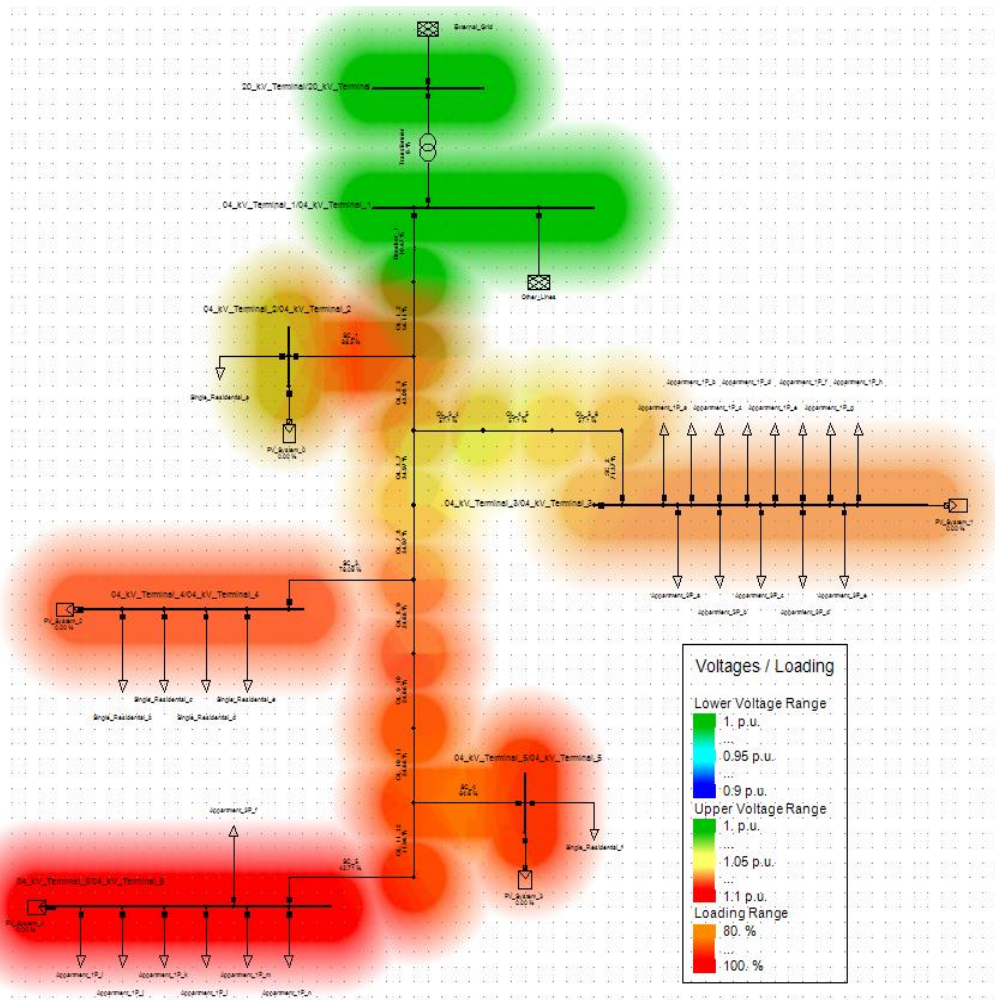


Ramp-rate control for PV generators

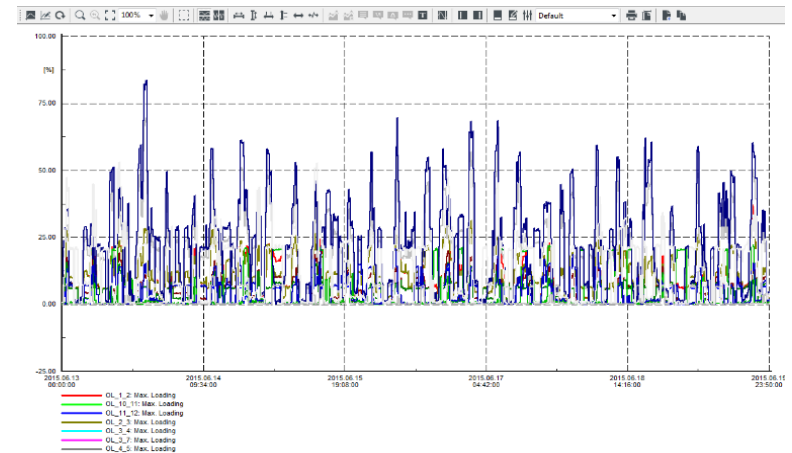


Reduction in amplitude of voltage fluctuations by 30%

# PV Hosting Capacity (PVHC) - simulated results

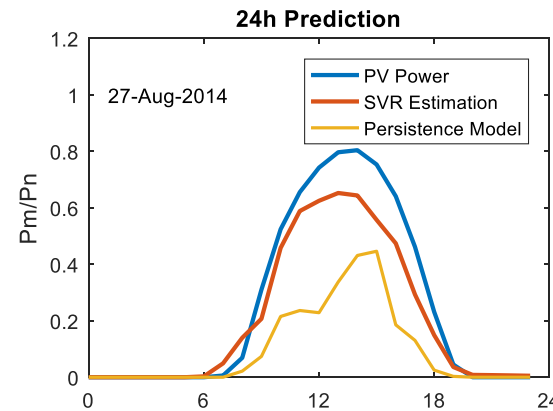
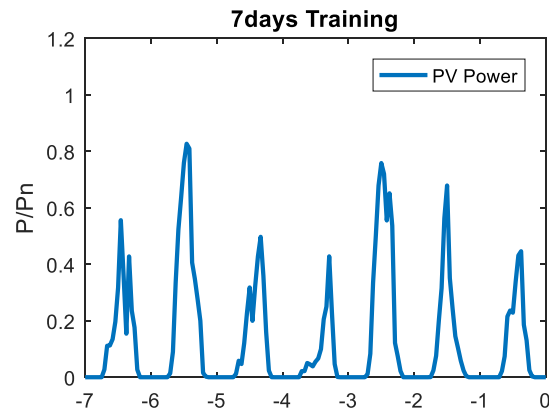
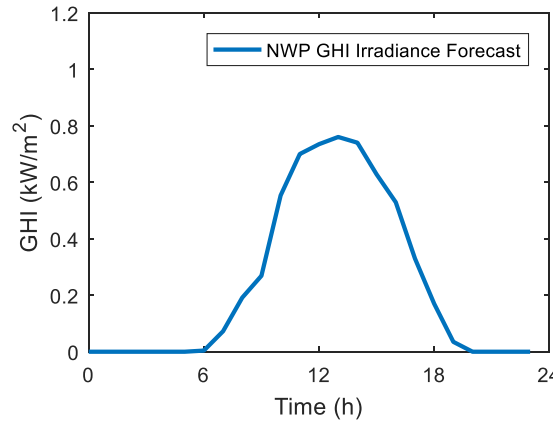
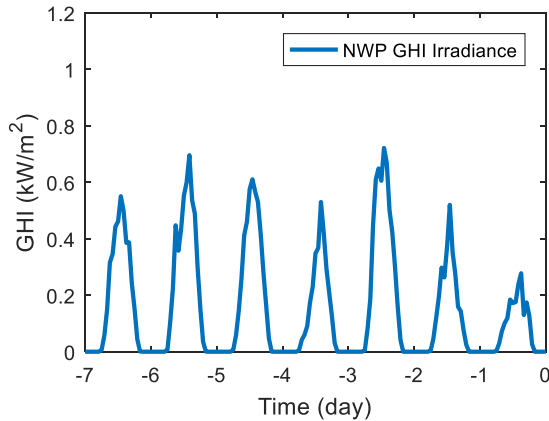


Case	Installed power [kVA]
Before PVHC	93.0
After PVHC	244.7 (+163%)
+ Load control	310.4 (+189.8%)
+ Inverter control	264.5 (+171.4%)
+ Load and inverter control	343.0 ( 203.1%)





# PV Power Prediction



Measurements from EURAC, Bolzano, South Tyrol

A Support Vector Regression (SVR) technique is used to predict a 24h ahead PV power based on solar irradiance forecast

Forecast error for the SVR and the Persistence Model (PM) benchmark :

	PM	SVR
RMSE	12-15 %	7-9 %
MBE	4-6 %	2-4 %

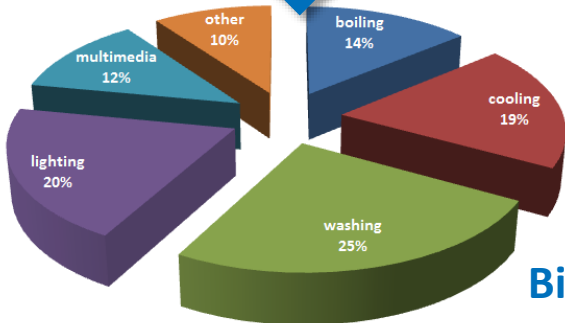
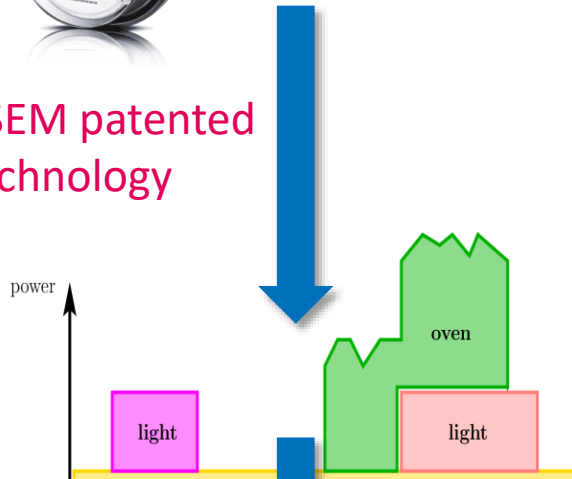
RMSE : Root Mean Square Error  
 MBE : Mean Bias Error  
 Daily errors averaged over one year

# Appliance load identification

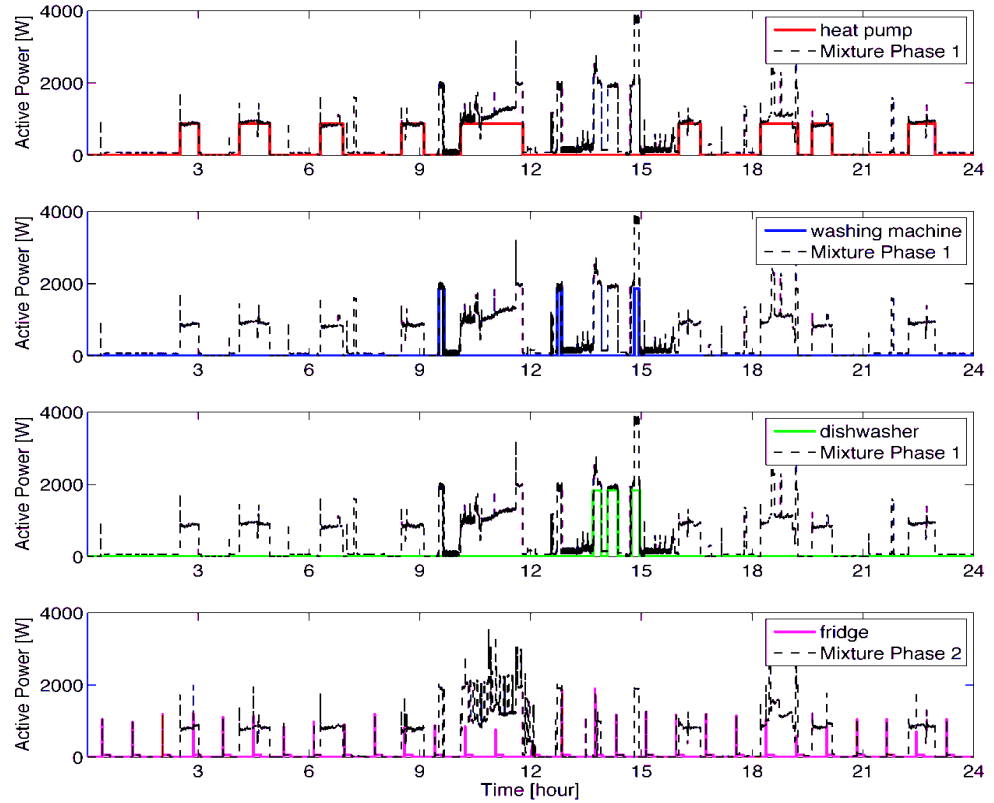


1Hz meter data

CSEM patented technology



Bill breakdown



# Thanks to my research teams



**M. Despeisse**



**L.E. Perret-Aebi**



**J. Bailat**



**S. Nicolay**



**A. Hutter**




**A. Alet**



# Public financial support and collaborations



 Schweizerische Eidgenossenschaft  
Confédération suisse  
Confederazione Svizzera  
Confederaziun svizra

Swiss Federal Office of Energy SFOE

Kommission für Technologie und Innovation KTI

Secrétariat d'Etat à la formation, à la recherche et à l'innovation SEFRI

 FONDS NATIONAL SUISSE  
SCHWEIZERISCHER NATIONALFONDS  
FONDO NAZIONALE SVIZZERO  
SWISS NATIONAL SCIENCE FOUNDATION

 Virage énergétique  
Programme national de recherche PNR 70

 MEYER BURGER

 SOLAXESS  
white solar technology

 INDEOTEC  
SWISS MADE

 BASF  
We create chemistry

 BLUEBIRD

 ÜSERHUUS  
BKW

+ many others

 nano-tera.ch

 viteos  
toutes vos énergies

 planetSolar

solar swiss connect

 SIG

 ine.ch  
RÉPUBLIQUE ET CANTON DE NEUCHÂTEL

 BCN

 Ville de Neuchâtel



ROW

