Photovoltaics

Christophe Ballif
Prof. EPFL, Director Photovoltaics laboratory
CSEM, PV-center
Neuchâtel

Activités de recherches et d'industrialisation

- Recherche de base
- Dispositifs avancés

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

EPFL- PVLAB

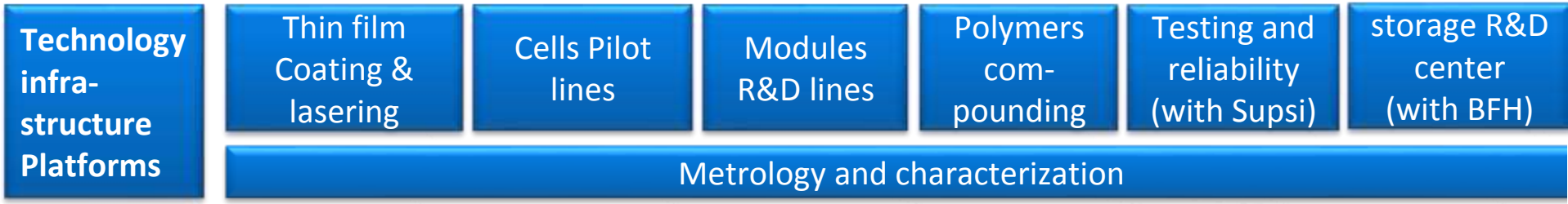
- Recherche appliquée
- Du labo à l'industrie

CSEM

PV-center (depuis 2013)

Infrastructures uniques

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













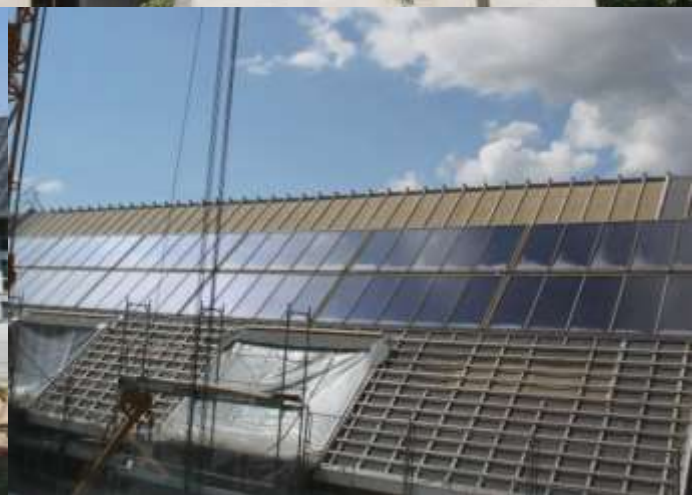

Les chemins du solaires

- **Passif**

- **Thermique**

- **Thermique avec stockage saisonnier**

→ Hot water or ground heating and energy recovery with PAC



[Swiss solartank www.2sol.ch]

Solaire thermique à concentration: lumière, chaleur, électricité

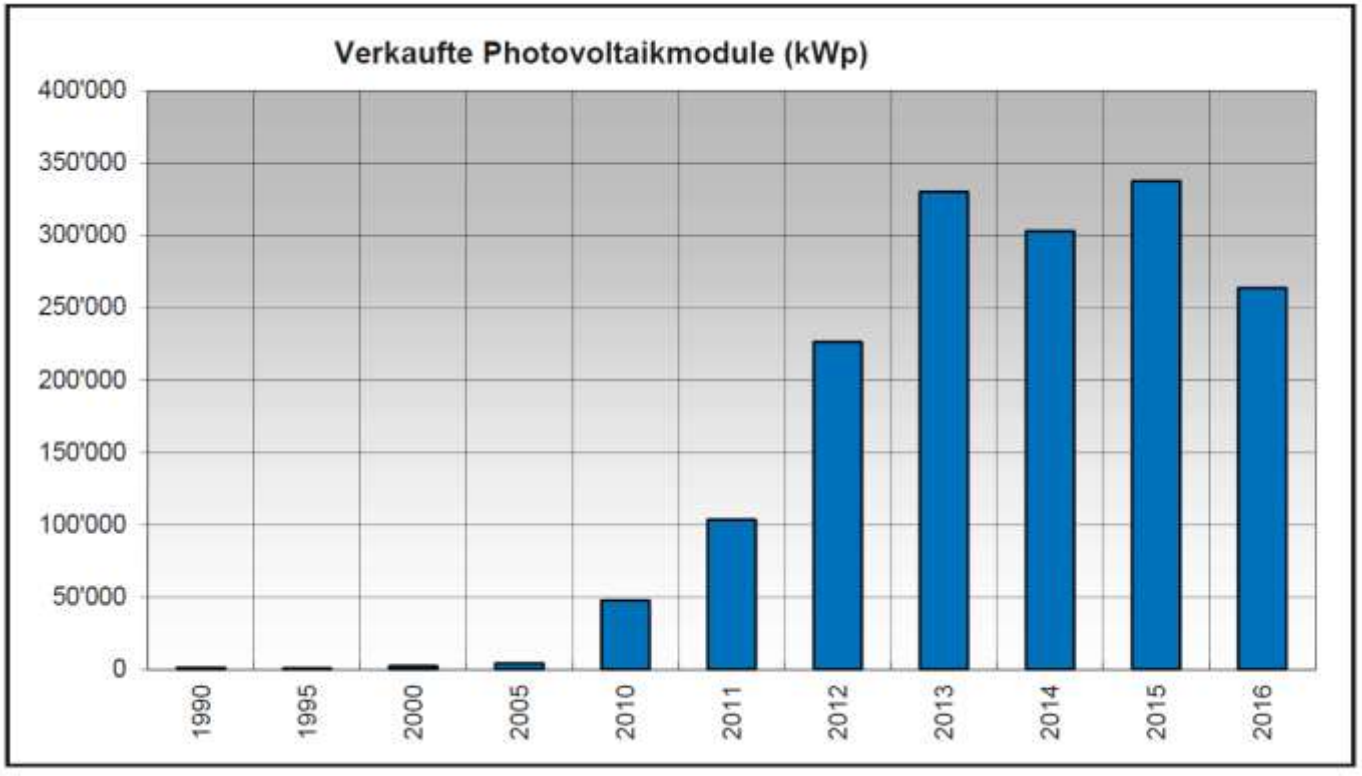
- 300°-600°C
- possibilité de stockage de chaleur !
- perspective pour kWh à ~ 7-10 €cts
- Système complex, rayonnement direct

Politics: mportant to reach 12-15 GW installed…

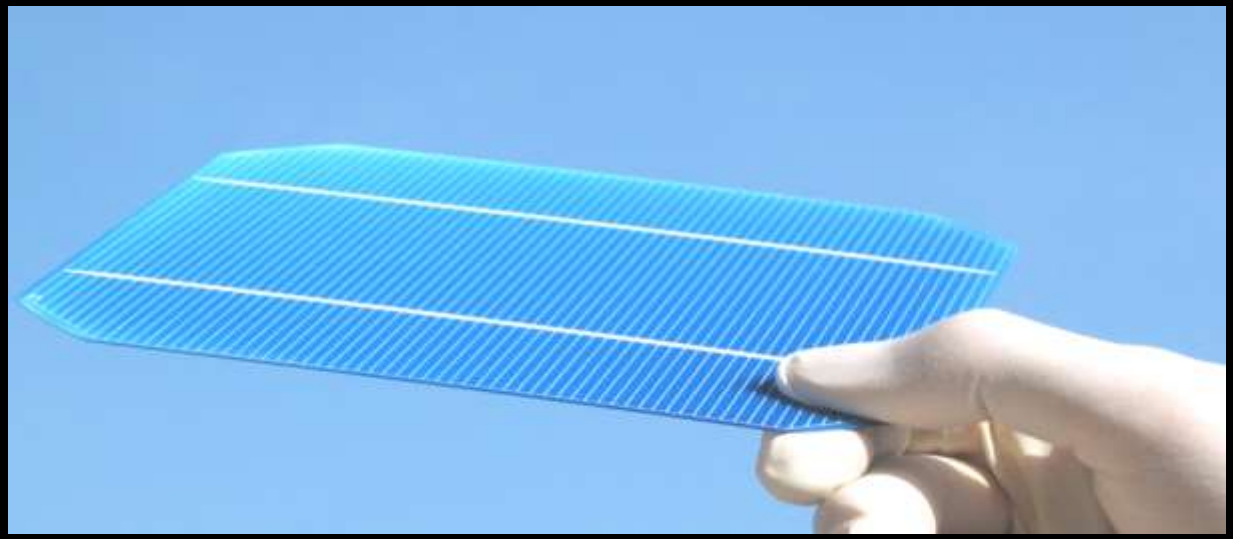
Solar in Switzerland

Target: 7 GW by 2030 (12% electricity) → install 400 MW per year from 2018…

12-14 GW by 2050 (20% electricity) → 300-400 MW (renewal)



What is a “standard” solar cell ?



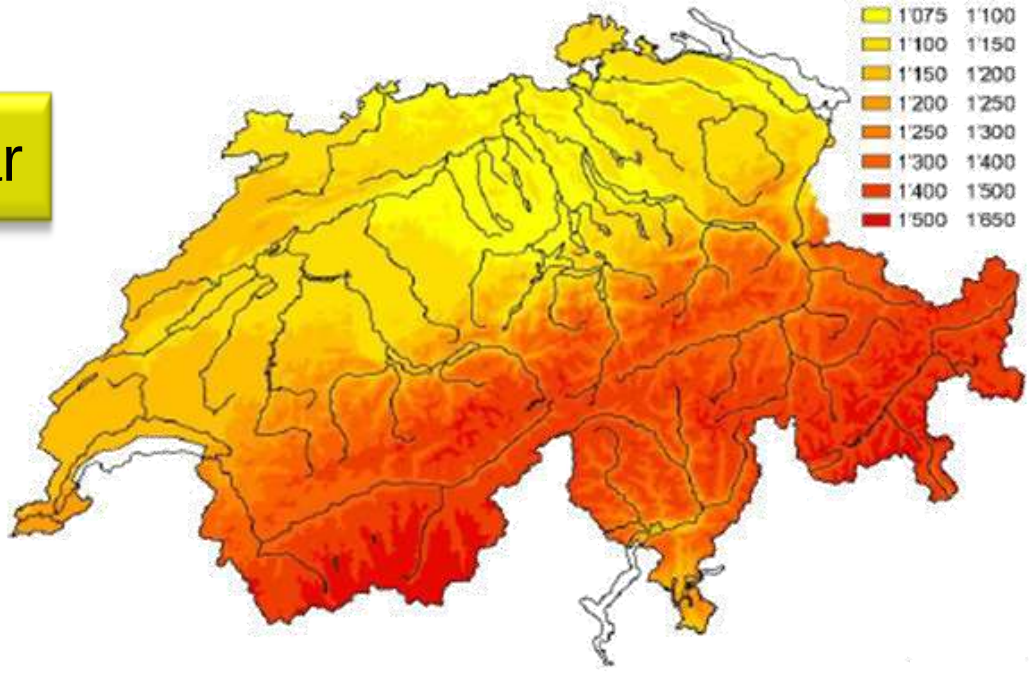
A transformed silicon wafer…

1998, 40 millions cells made (at 25 CHF/piece)

In 2016, 12 billions (at 1.5 CHF/pièce)

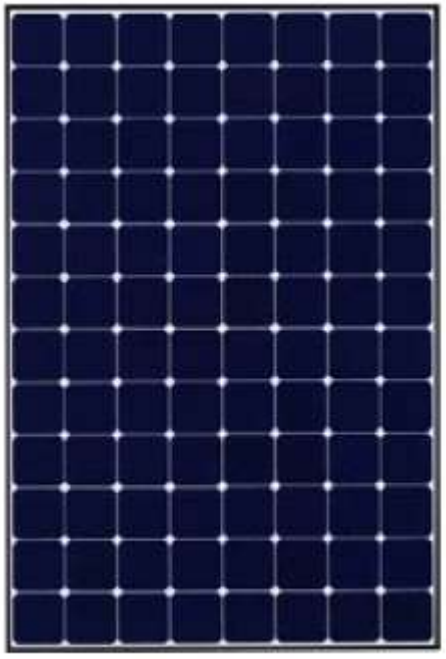
Intensité solaire

1000-1500 kWh/m^2 per year



1 baril of oil
(159 litres)
per m^2 et per year

Density of solar energy



SPR-X22-360

X22 SERIES

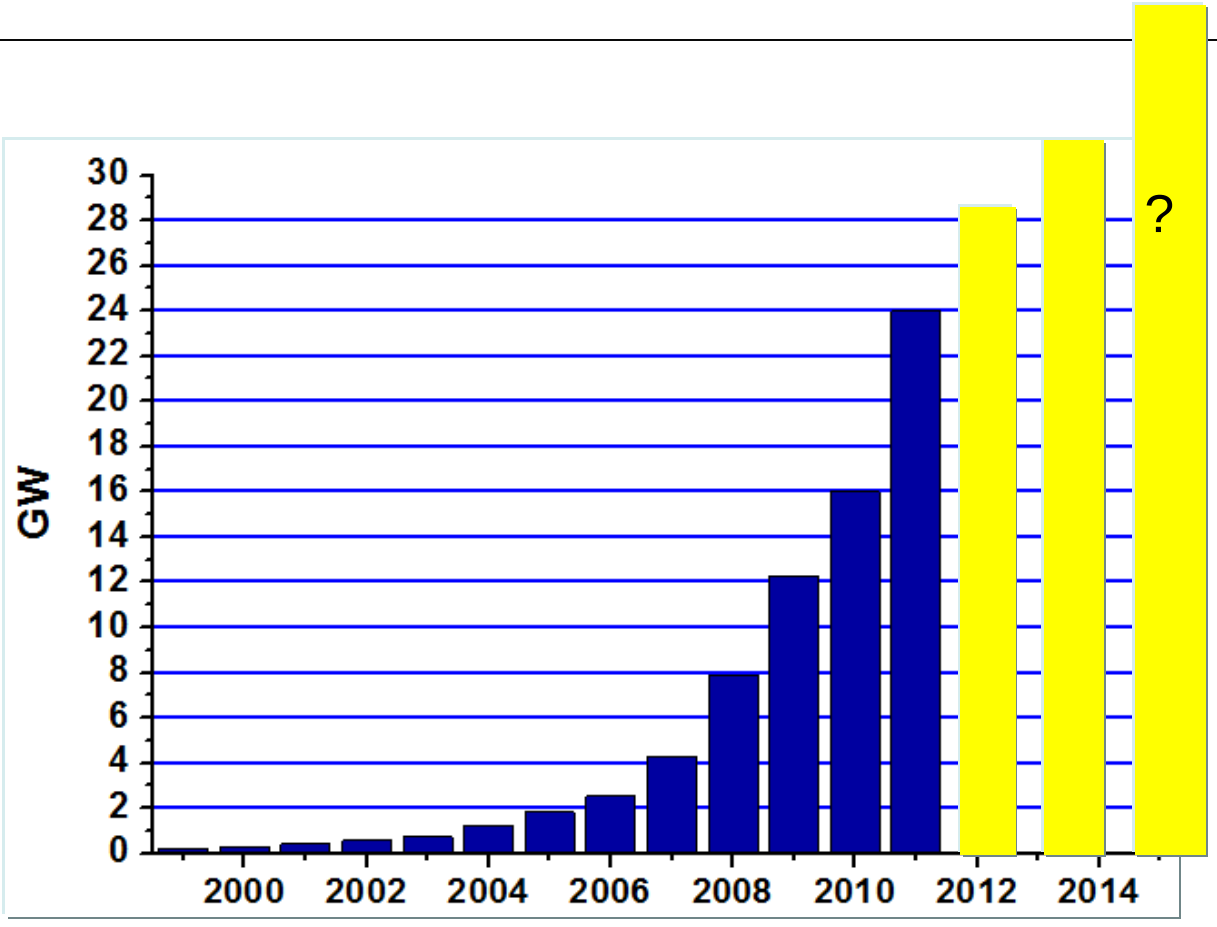
With 10 m2

→ 2600 kWh in Engelberg

→ 13'000 per year (20kWh/100 km) with the most powerful e-car

Costs of Solar?

Global solar market



Fabrication de panneaux solaires annuelle

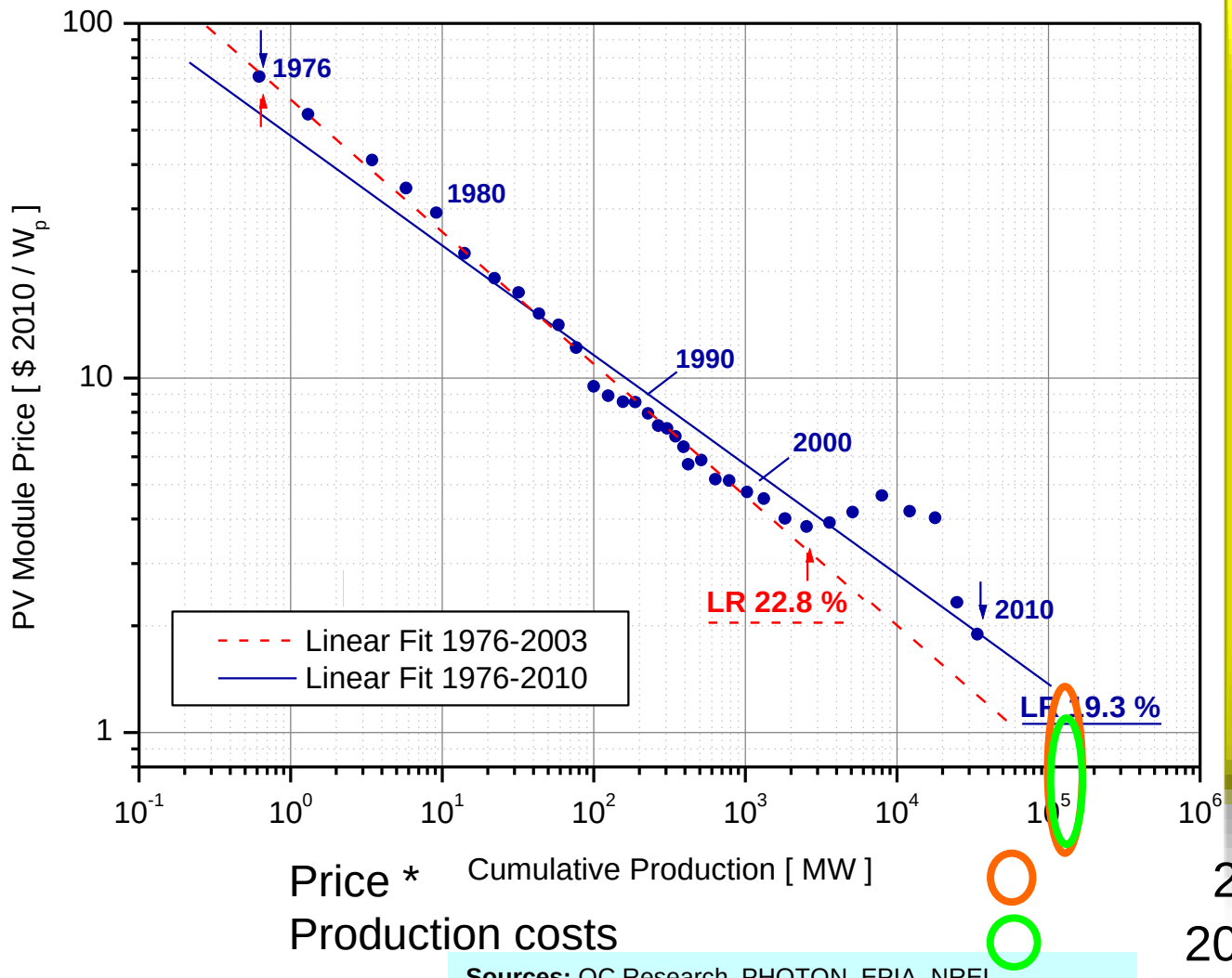
Source
Solar Buzz/Photon Magazine

A strong volume growth market thanks to policy first: Allemagne, Espagne, Japon, Italie, France, …

Added modules:
0.15 GW en 2000
37 GW en 2013
55 GW en 2015
65 GW en 2016

At noon:
65 new
Nuclear Power plants

Learning curve for PV module



Effet d'échelle
Si on double la production cumulée

-20% de réduction de prix

Price *
Production costs

2017 ~ 0.4-1.2 CHF/Wc

2017 ~ 0.4-1.2 CHF/Wc

Sources: QC Research, PHOTON, EPIA, NREL, Solarbuzz, Strategies Unlimited, P. Maycock

*typically ordering 1 MW modules

PV-lab IMT NEUCHATEL

csem

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Base material price

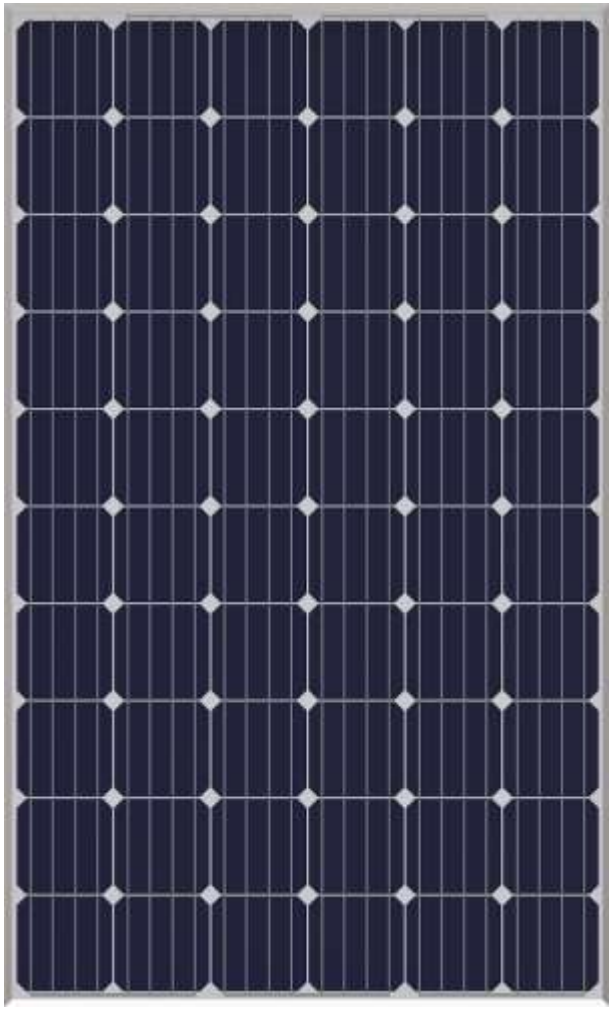
Nominal power given under 1000 W/m2 of light
At 25°C

A standard c-Si pannel at 17 % efficiency → 170 W/m2 nominal power costs

65 CHF/m2

1 m2 will produce 6500 kWh over 40 years in Engelberg…..

1cts/kWh



Cost of solar electricity

Direct cost of solar electricity

Larges power plant
in Sunny country

0.34$/Watt modules
0.2 $/mounting/cable (1 axis)
0.06$/Inverter-Grid connect
0.2$/ engineer/others
Total invest: 0.8$/W

2kWh/W annually
1.4% maintenance, 25 years
4% interest rate

3.2 cts/kWh

10 kW added
rooftop PV in CH

0.6$
0.2$
0.2$
1 $
Total invest: 2 CHF/W

1.1 kWh/W annual
2% op. tax, 30 years
2% interest rate

12 cts/kWh

Direct costs for large system in Sunny country

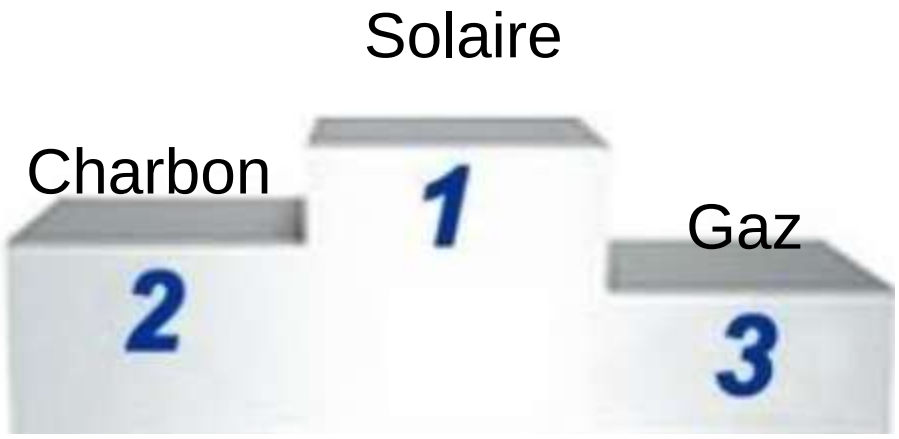
Suisse: now typically 8-10 cts/kWh

South EU/USA: 5-7 ct/kWh

Best places: 2.7-4 cts/kWh

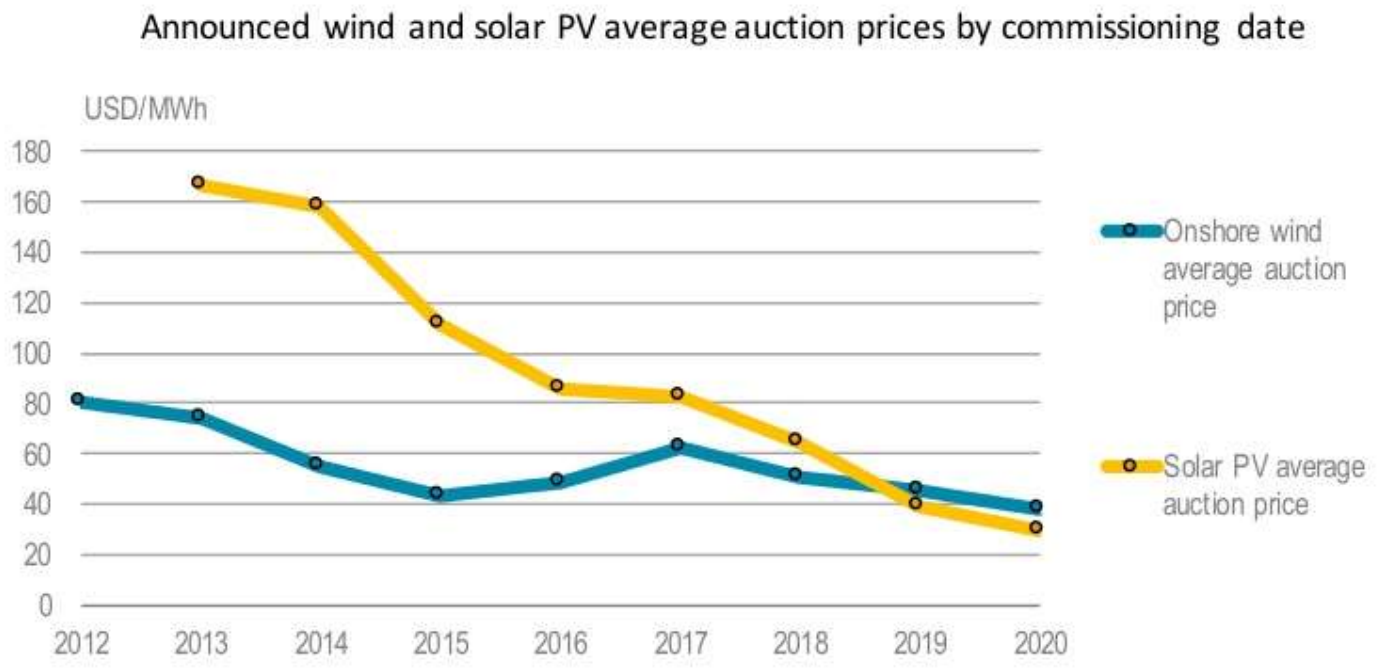
In more and more places solar is the cheapest source of electricity

Without costs of CO_2



Renewables 2017, IEA: Wind and Solar = highest new capacity added !

Competition driving costs down



Price discovery through competitive auctions effectively reduces costs along the entire value chain; Auctions with long-term contracts will drive almost half of new capacity growth over 2017-22

The multiple curses of solar electricity

Unfair competition with CO2 rich energy sources (e.g. marginal cost of coal in EU)

Self destroying market with noon peak production if no agreed pricing

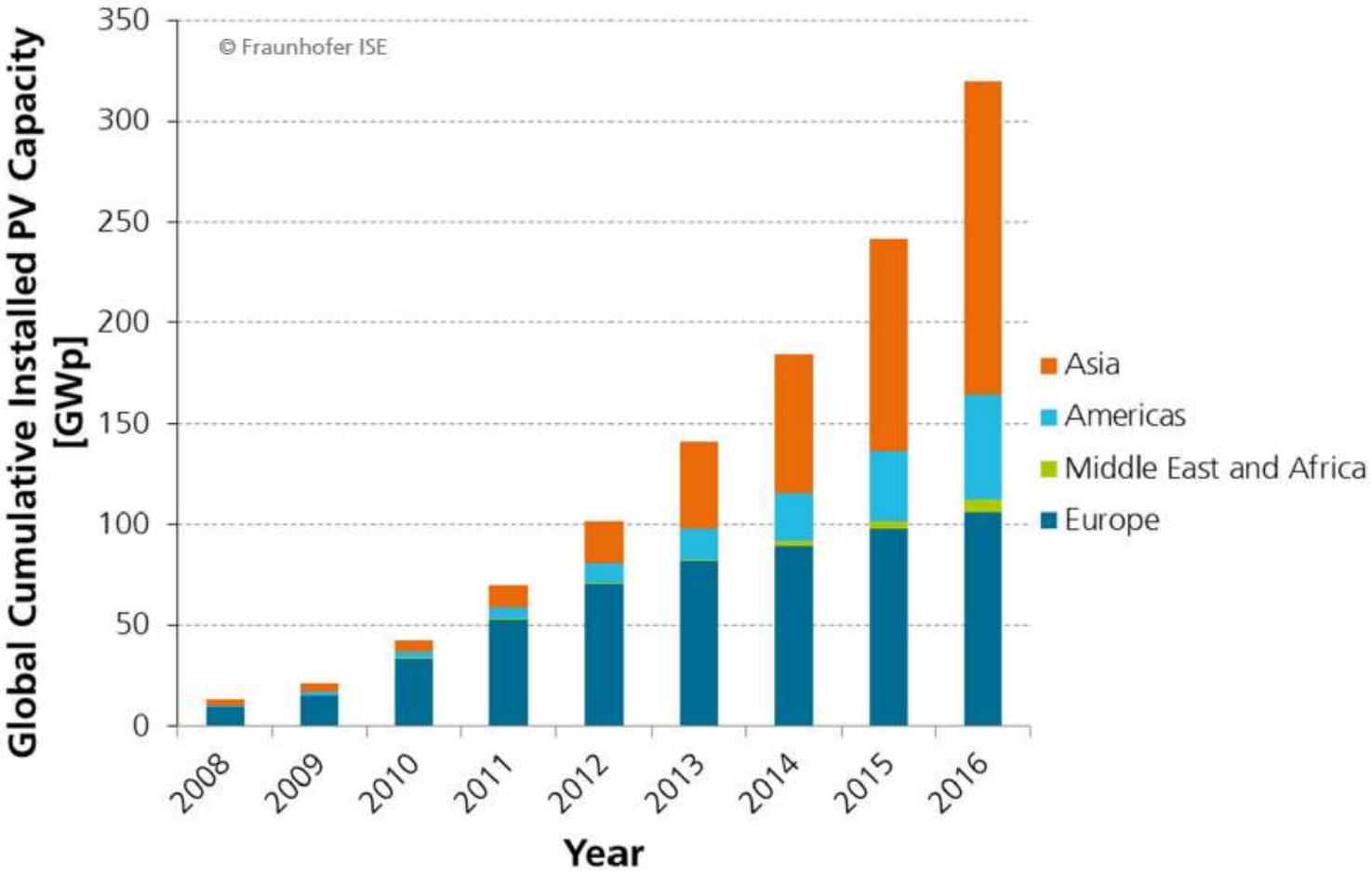
Costly access to the grid/low feed-in tarifs

Value
≠
Direct cost

Slightly more complex energy system

csem

Retour sur les installations mondiales…..



Chine,
Inde,
USA,
Chili….

Annual PV installation by region until 2016 (Source IHS/PSE).

Nuclear reactor / Kostenentwicklung

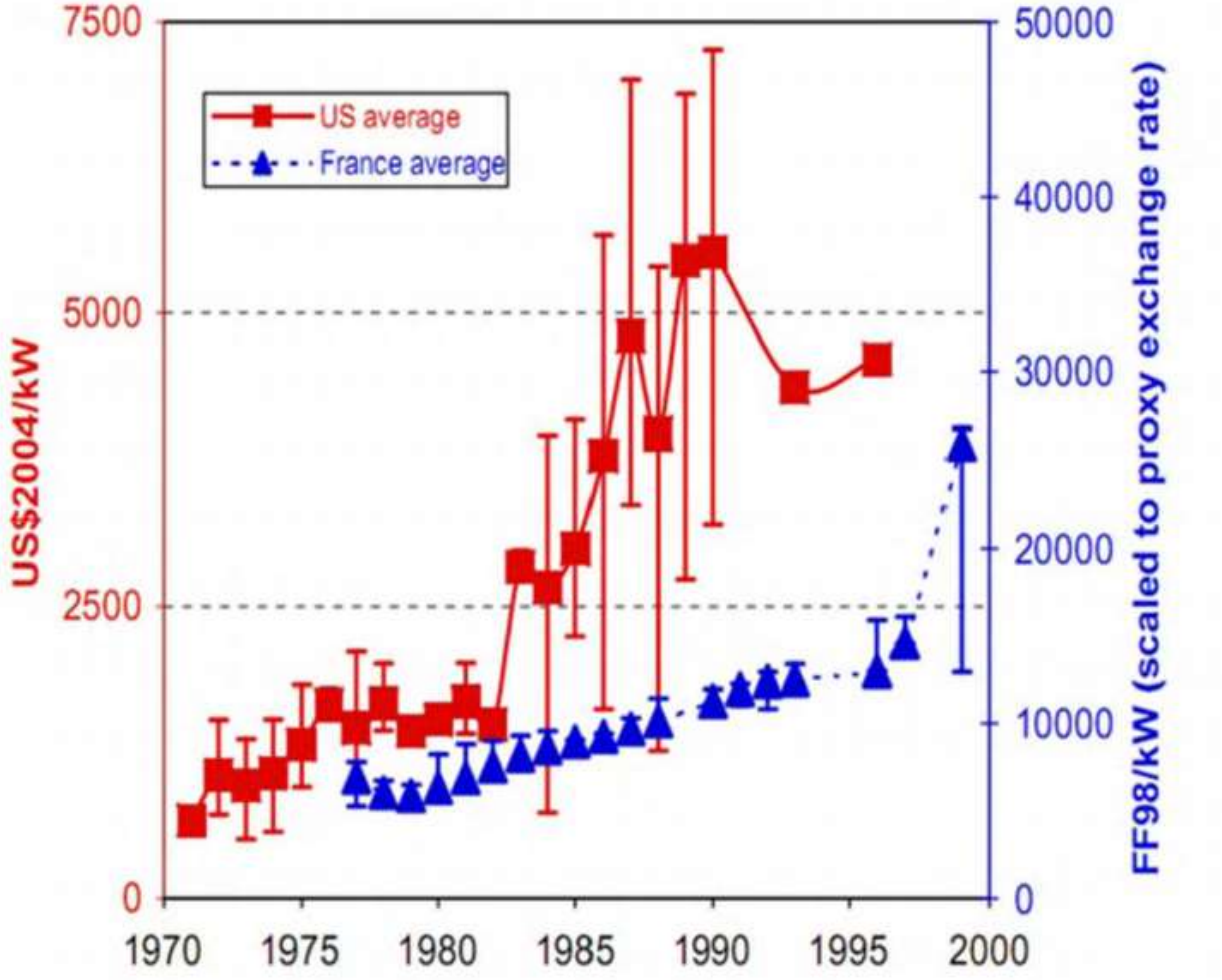


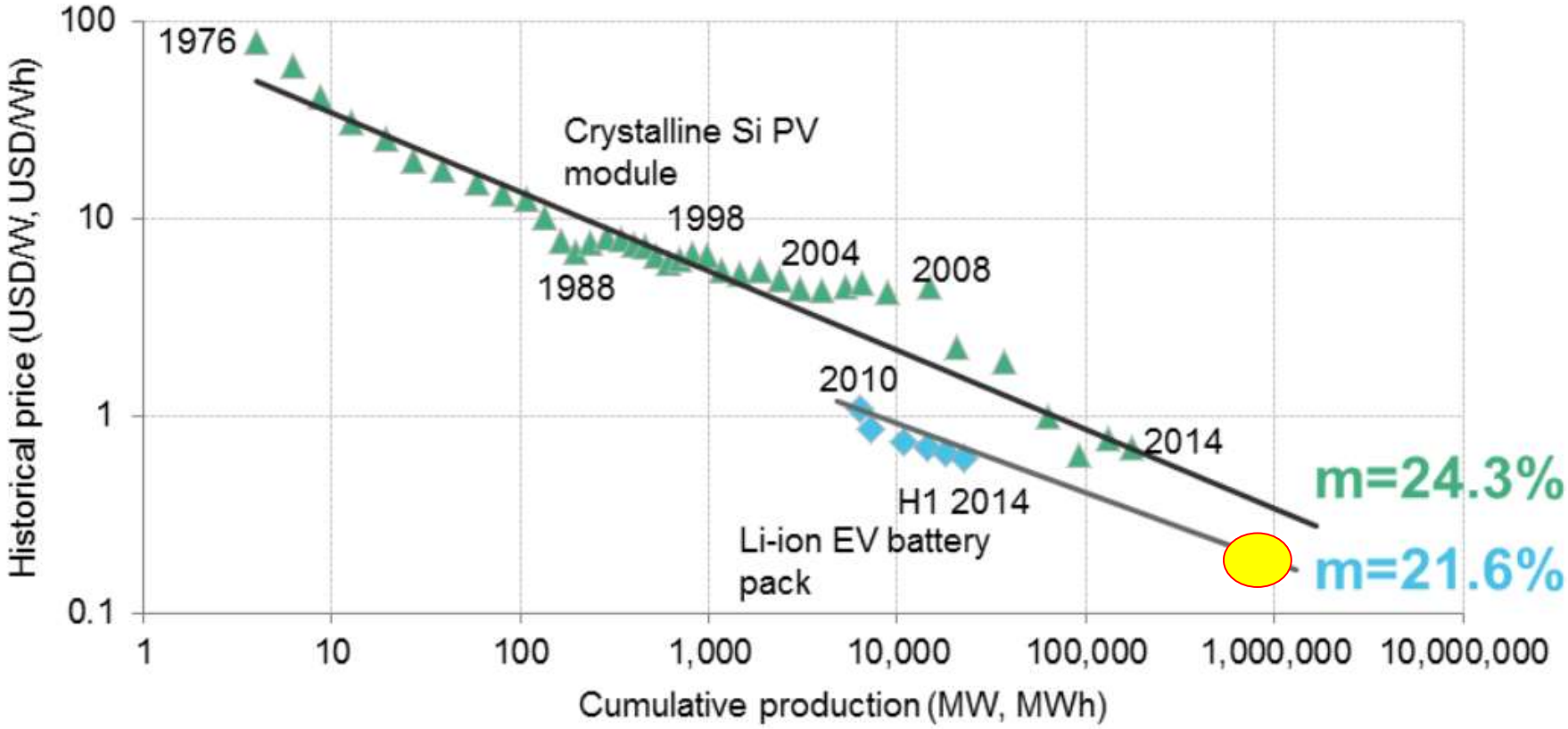
Fig. 12. Comparison of French (FF98/kW, this study) and US (US$94/kW, Koomey and Hultman, 2007) nuclear construction costs, average and min/max per reactor completion year (year of entering into service in US, year of first criticality in France, cf. Fig. 9). The different metrics are scaled in proportion to yield an

A. Grubler / Energy Policy 38 (2010) 5174–5188

No volumes:
No-price going down

Le prix des centrales nucléaires

Stockage de l'électricité



Même courbe d'apprentissage que le photovoltaïque !

Growing specialised markets

4 million solar products sold by members of the Global Off-grid Lighting Association (GOGLA) in the second half of 2015

2 millions in Sub-Saharan Africa.

+Micro-credit
+Smart Phone payments

Application fields

Powerpure
technologies for lowest cost solar electricity

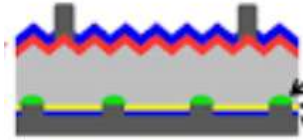
Elegance and architecture
transforming building and cities with solar

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

E-tonomy
energy scavengers and ubiquitous power sources

Explore
customized PV products from the water to the air

Power pure : Trends in mainstream crystalline PV, 95% of the market



- 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

POWERPURE: cellule à héterojonction

2005 2008 2009 2011 2013 TODAY

First high efficiency solar cells

Hosting and transfer of technology to Roth&Rau Switzerland

Industri-alisation phase

First production lines and tools sold

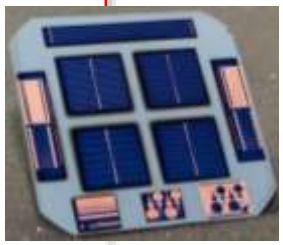
Large scale demonstrator

Swiss Electric Research award 2007

19.2%

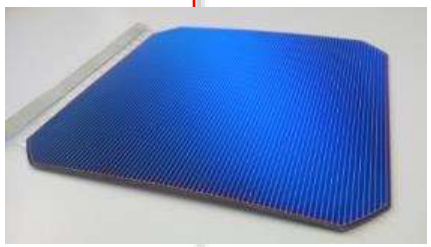
Creation Roth and Rau Switzerland

22-23 %



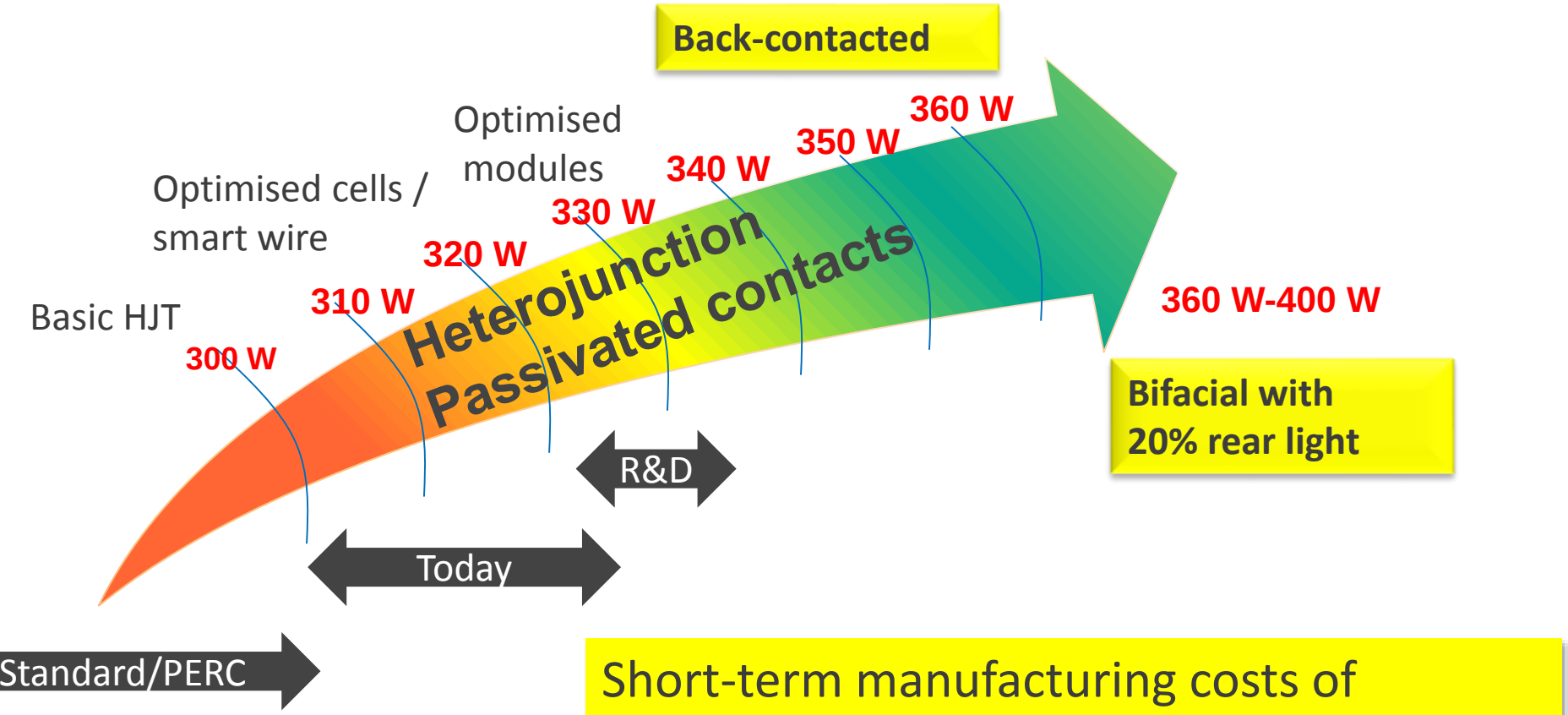
Meyer Burgers Acquires Roth&Rau

22-23 %



MEYER BURGER

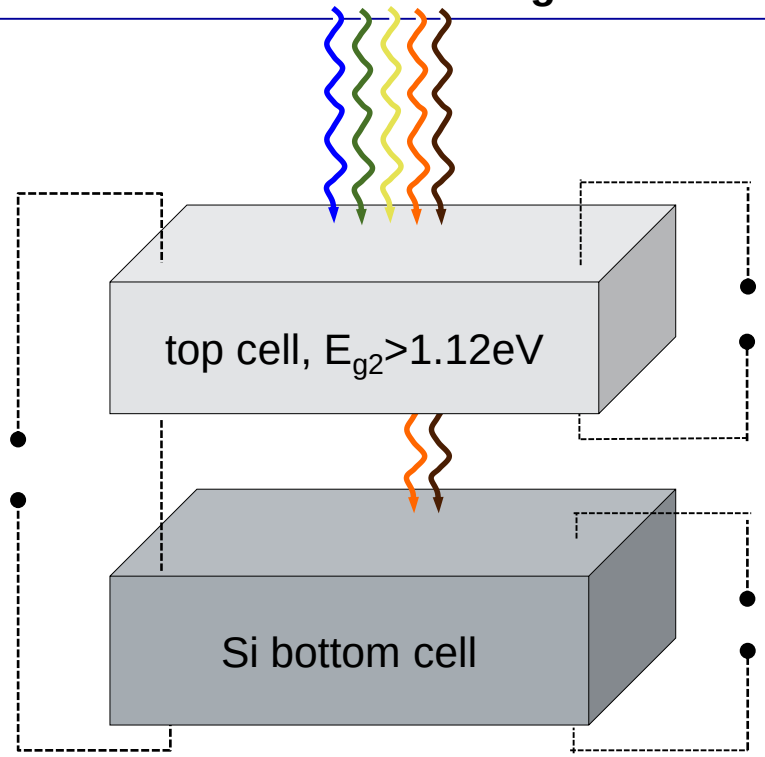
Future of c-Si SHJ modules, 60 cells, 6''



Short-term manufacturing costs of ~0.25-0.35 €/Wp at 20% efficiency
Potential for further cost reductions

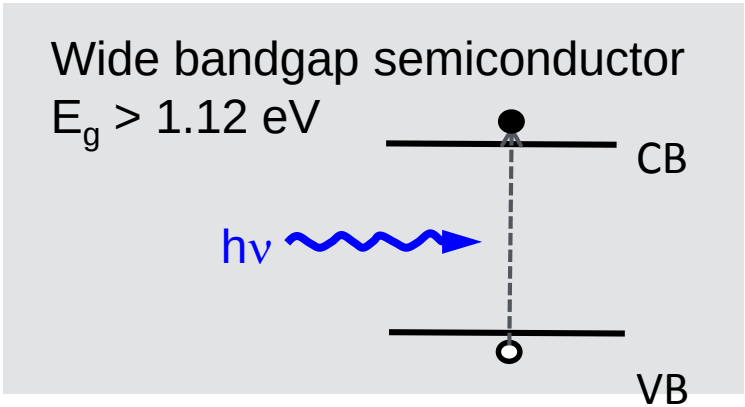
Cellules «tandem»: 2 cellules l'une sur l'autre

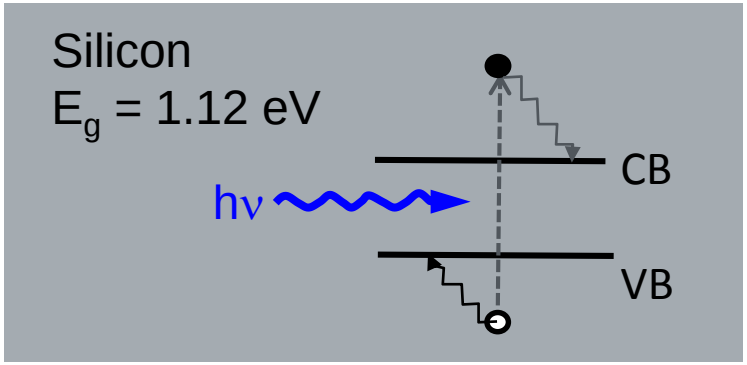
Couple the Si cell with a top cell of higher band gap energy
→Reduction of thermalization losses
→Generation of additional voltage



serially connected (2-terminal)

Independent operation of cells (4-terminal)

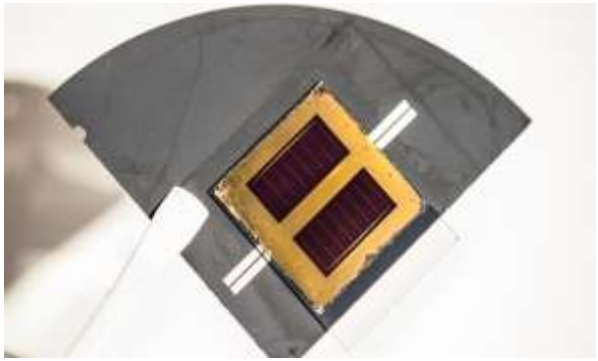


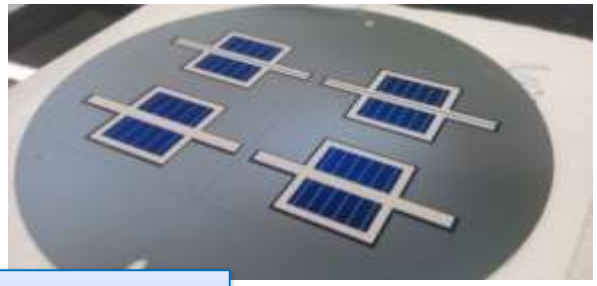


Record next generation devices

Custom designed small HJT cells
4 terminals III-V /c-Si tandem,

> 32.8 % Record du monde

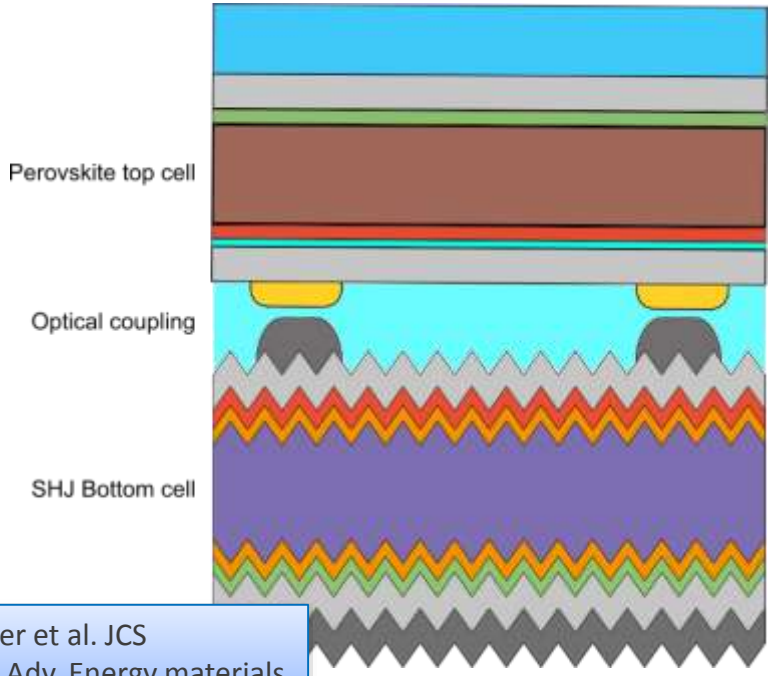




S. Essig et al. IEEE JPV 2016
S. Essig et al.Nature Energy 2017

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

25.6% in-house

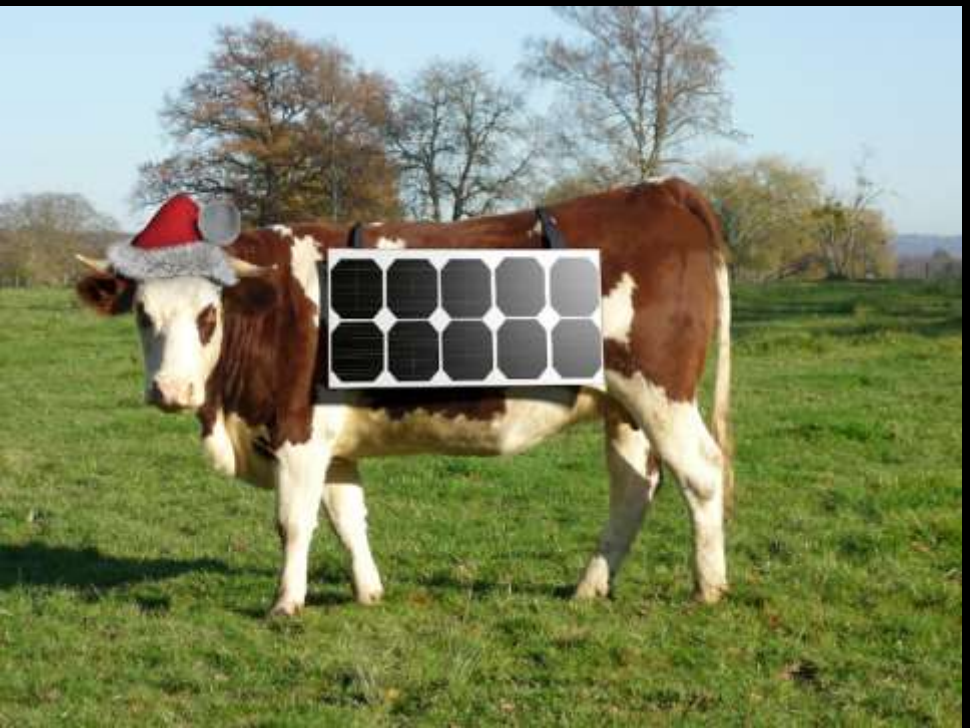


J. Werner et al. JCS
F. Sahli, Adv. Energy materials

ELEGANCE

Switzerland, sensitive to acceptance in Rural and Urban Environment

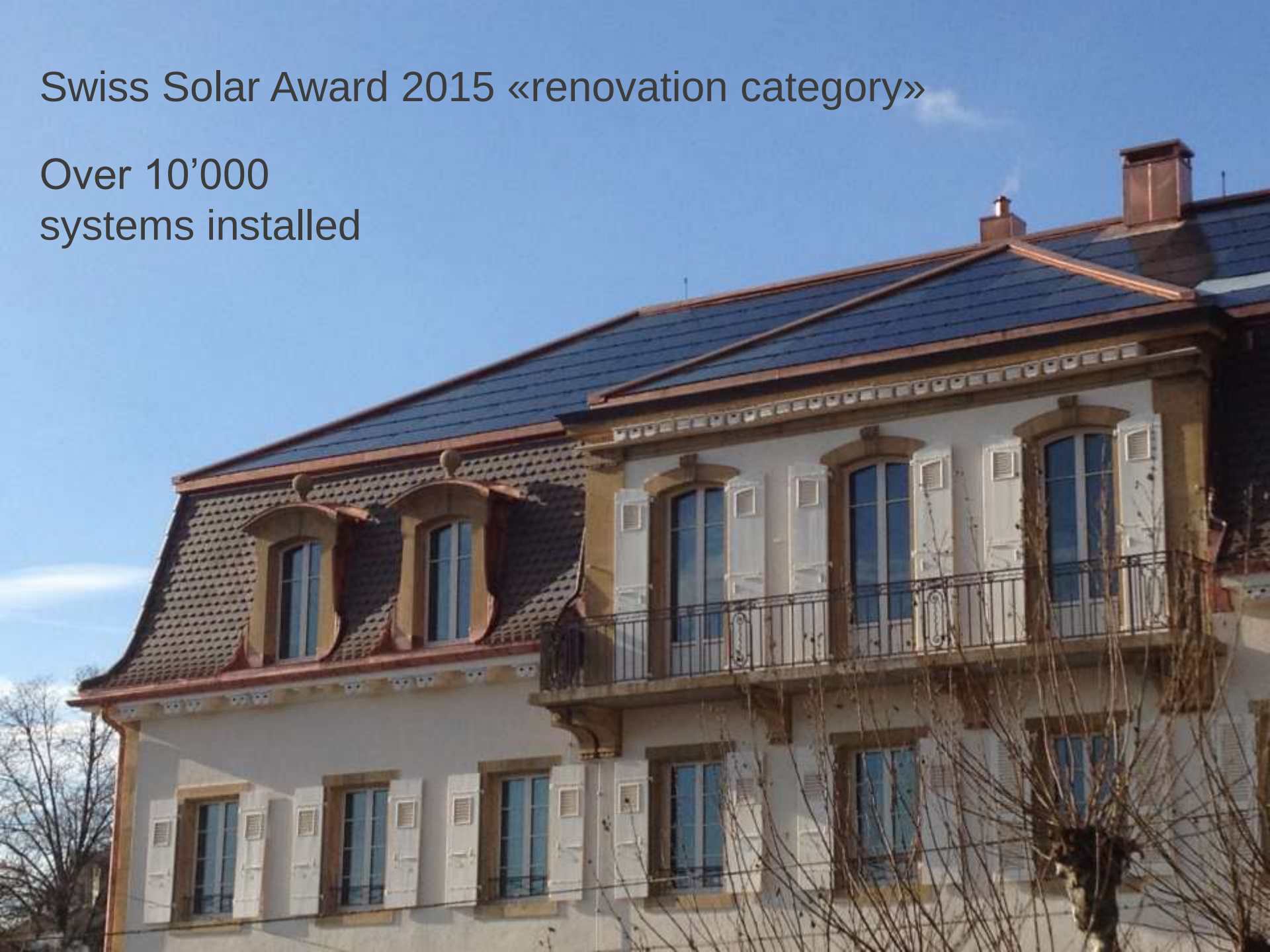
Sensitive to aesthetics



Integrated «Megaslates»

Swiss Solar Award 2015 «renovation category»

Over 10’000
systems installed




FREE SUNS
SOLAR ENERGY

DESIGNERGY®

structurally integrated solar building solutions

Aesthetics in PV

Thermal Insulation

H2O-tightness

Structurally tough

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

ÜSERHUUS

csem

Photovoltaic in buildings

Demonstration project in Switzerland

csem

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

Simulation

ISSOL

ÜSERHUUS

csem

White photovoltaic modules

A new building material

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

➢ **A new building material**

SOLAXESS
white solar technology

1st generation product with

ISSOL

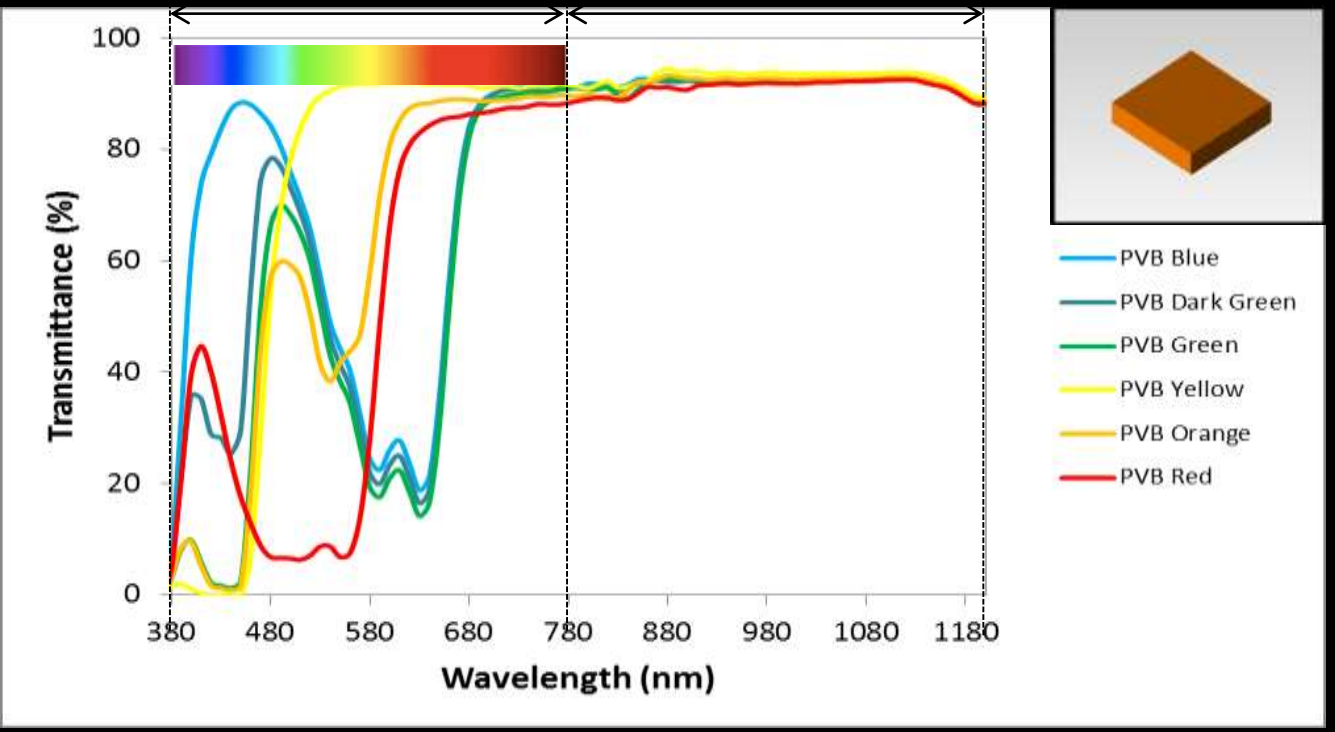
csem

Intensive Field testing

csem

Colored photovoltaic modules

Next step



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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‡

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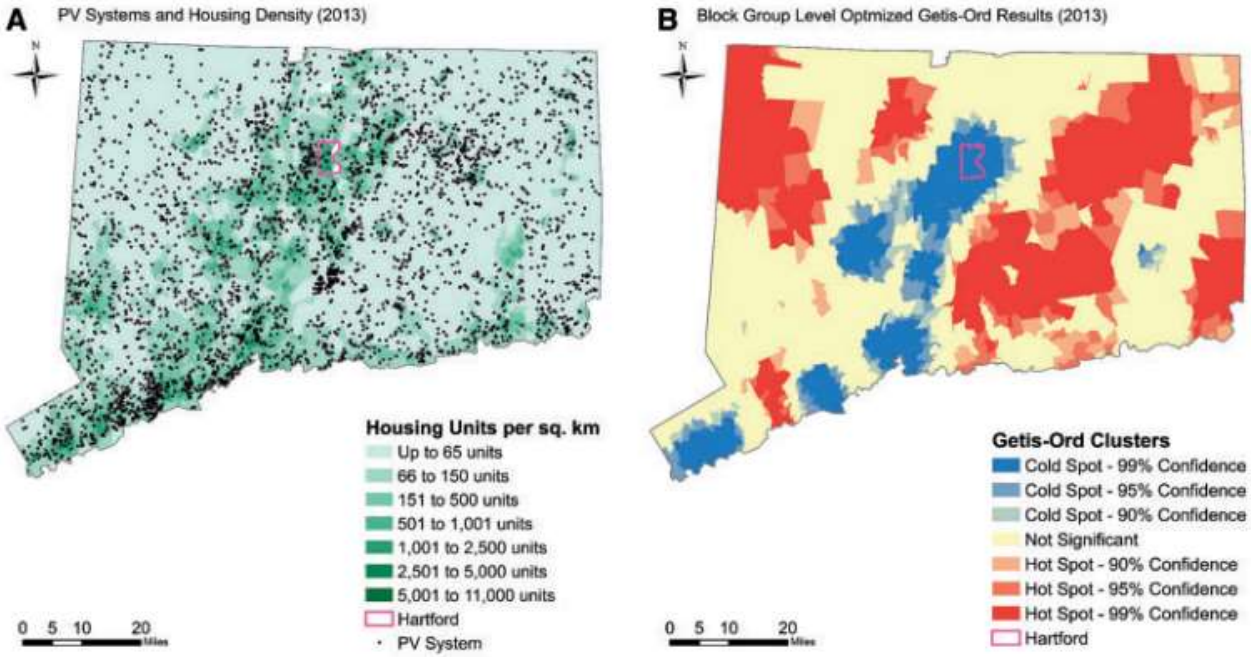
**Yale School of Forestry & Environmental Studies, Yale University, 195 Prospect St, New Haven, CT 06511, USA
†Corresponding author: Kenneth Gillingham, School of Forestry & Environmental Studies, Department of Economics, School of Management, 195 Prospect Street, New Haven, CT 06511.
email <kenneth.gillingham@yale.edu>

Influence your neighboors ….

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



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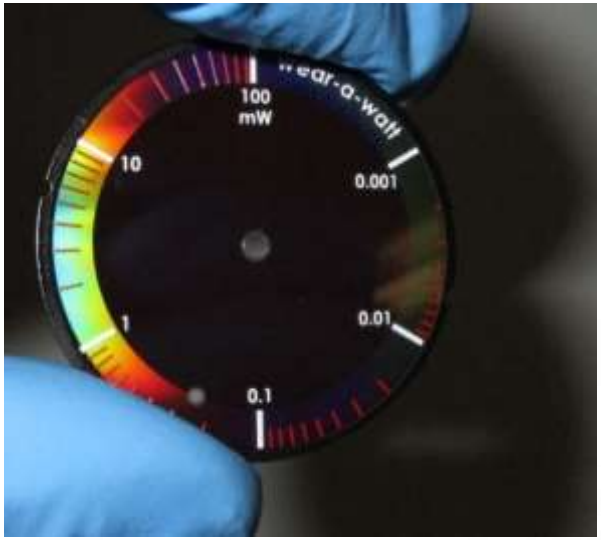
Connect



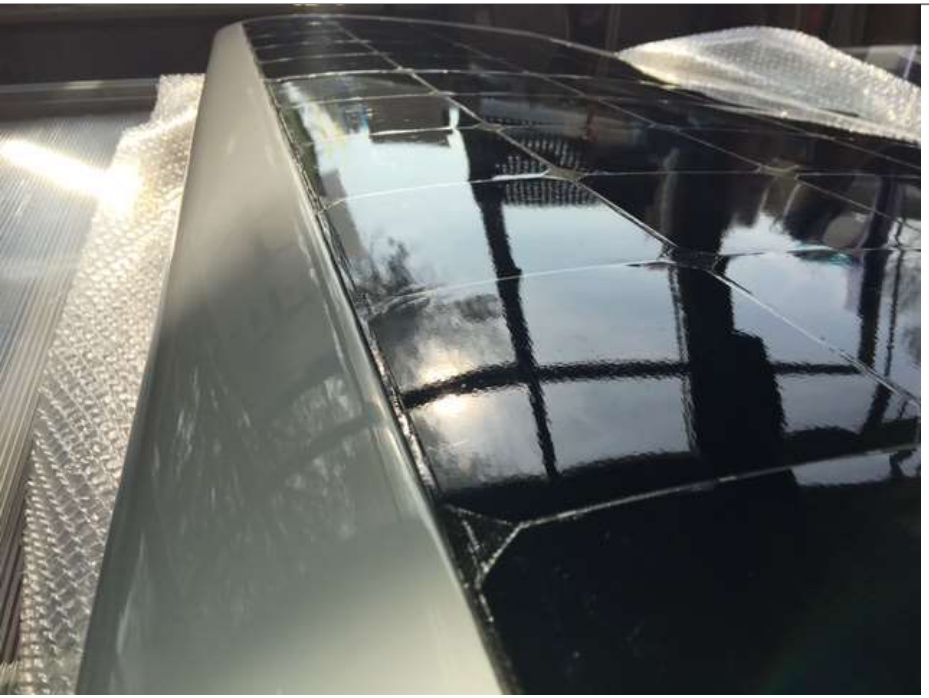
EXPLORE


© Reuters

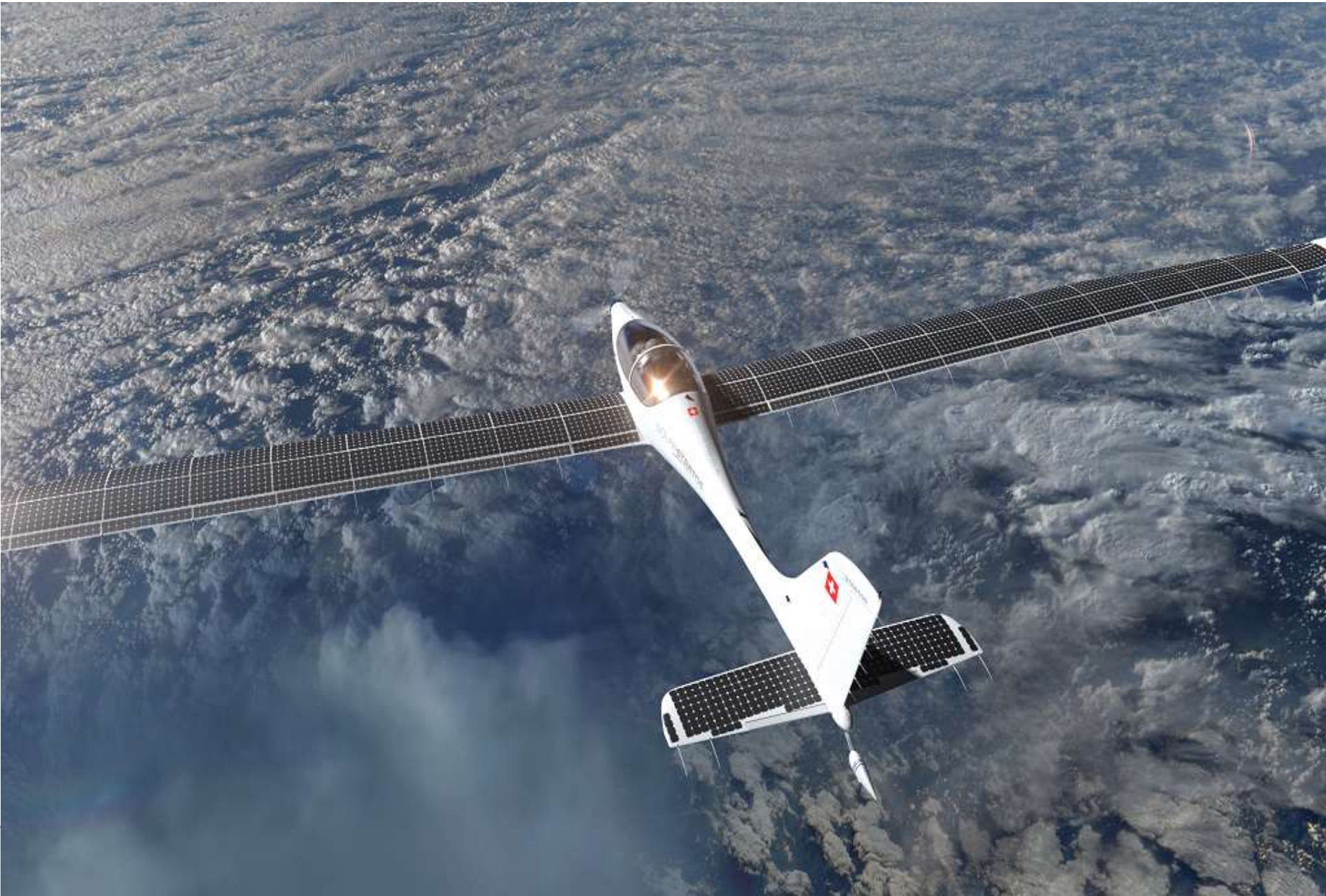
EXPLORE

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)



Solar Stratos… at the edge of space



Solar Stratos… at the edge of space

- To which extent can you color PV ?

The Kaleo Project ….

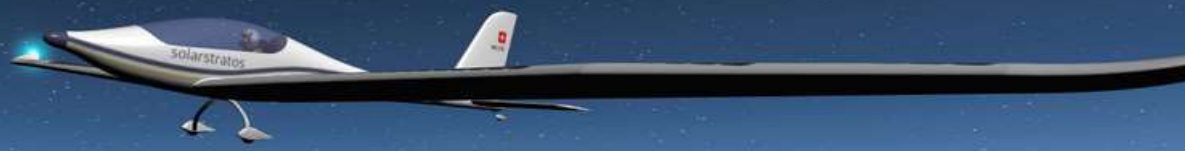
csem


Banque Cantonale Neuchâteloise


Banque Cantonale Neuchâteloise

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*



Merci pour votre attention !

Solarstratos

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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

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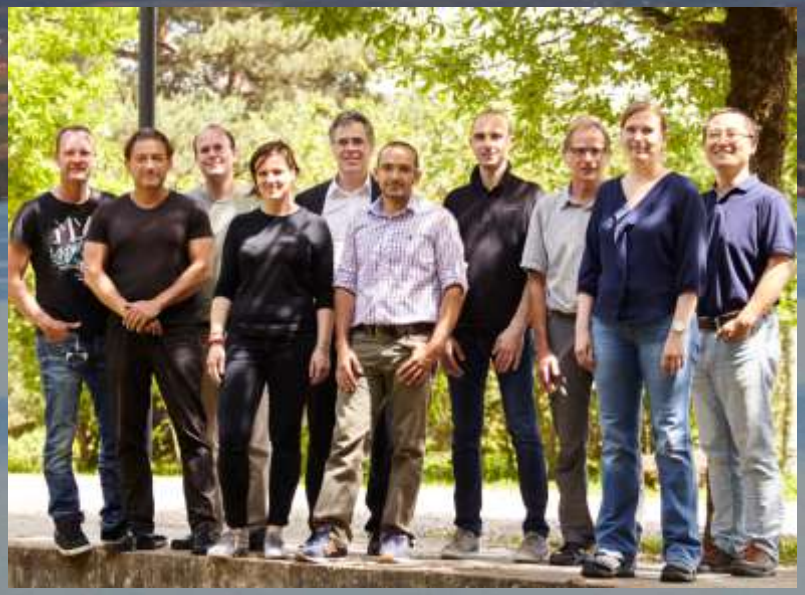

Kaleo team. L. E. Perret-Aebi et al

Some 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

nano-tera.ch

viteos
toutes vos énergies

planetSolar

solar swiss connect

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BCN

Ville de Neuchâtel

European Commission

FP6, FP7
H2020

cea

Fraunhofer ISE

Univerza v Ljubljani

imec

ISFH

HZB Helmholtz Zentrum Berlin

EMPA
Materials Science & Technology

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Berner Fachhochschule

Scuola universitaria professionale della Svizzera italiana
SUPSI

+ many others

ROW

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Australian National University

THE UNIVERSITY OF CALIFORNIA BERKELEY 1868

ARIZONA STATE UNIVERSITY 1885

+ many others

AIST

Novaton (CH)

Solar photovoltaic islands, on over-pressurized membrane can cope with waves 2-7 m (under developments),

DHP (CH)

Horizon
deployable
PV systems, over streets, parking, water,….

Charging EV station

Le rôle de l'Eolien et du solaire en Suisse

Scenario
Gunzinger
EPFZ
SCS