



Etat des lieux et enjeux du photovoltaïque aujourd'hui

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Switzerland

Order of magnitude

Sun intensity 1000 W/m^2

In CH ~ 1000-1500 full hours

1000-1500 kWh/m² per year



Up to one barrel (159 litres) of oil per m² per year

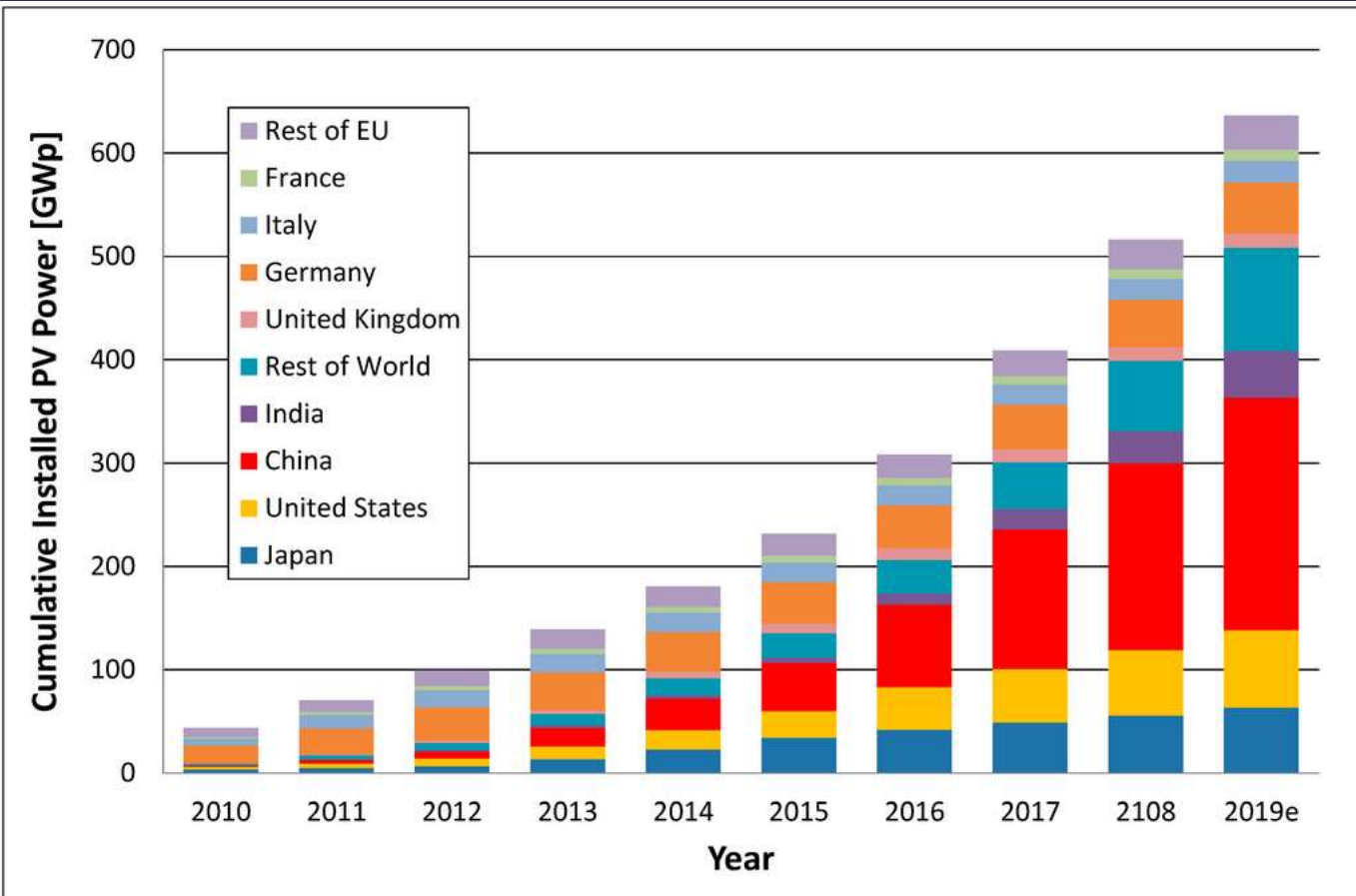
*1 liter gasoline ~10-11 kWh chemical energy



Le solaire, une énergie
renouvelable à bas
coût



Capacité installé mondiale à 630 GW (end 2019)

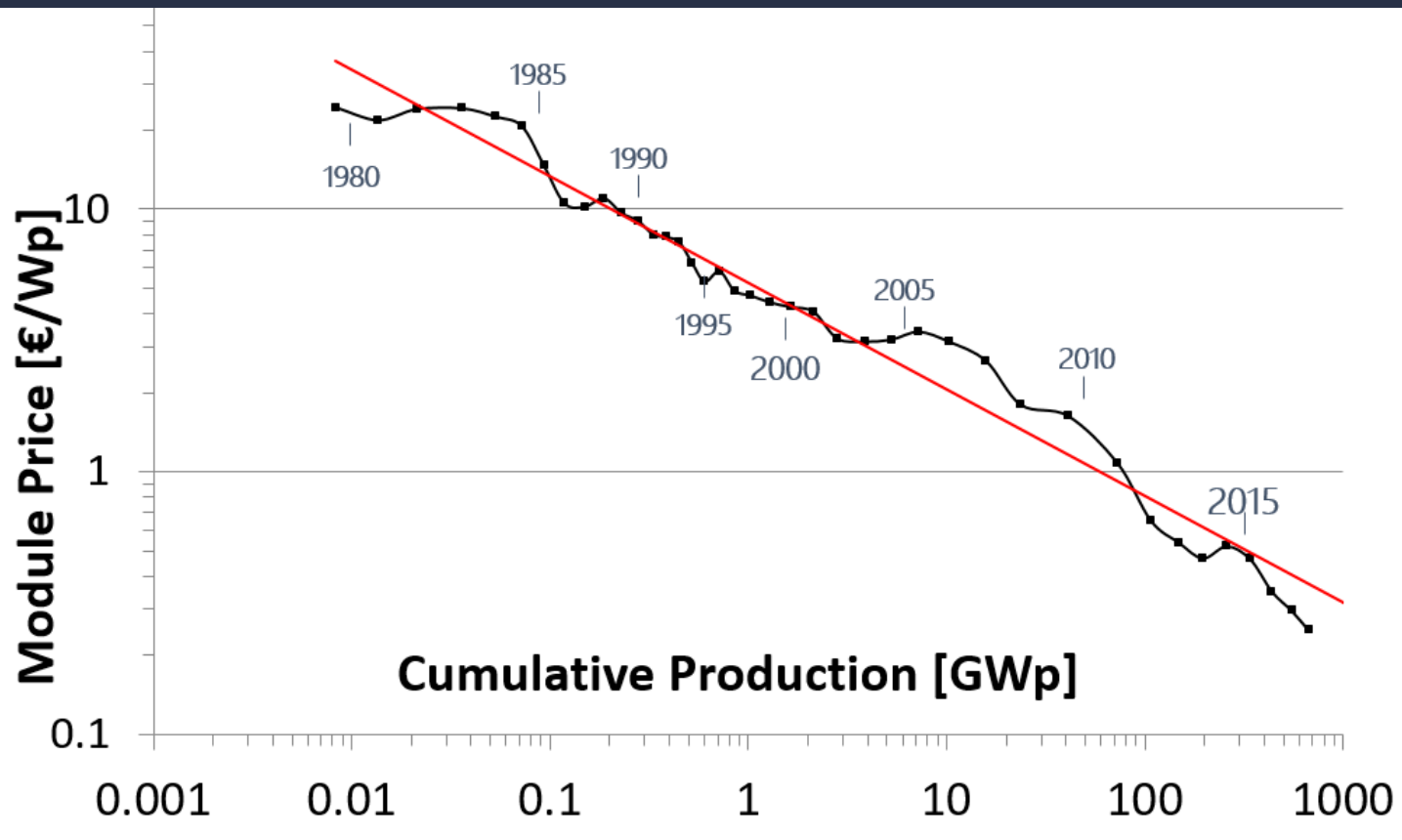
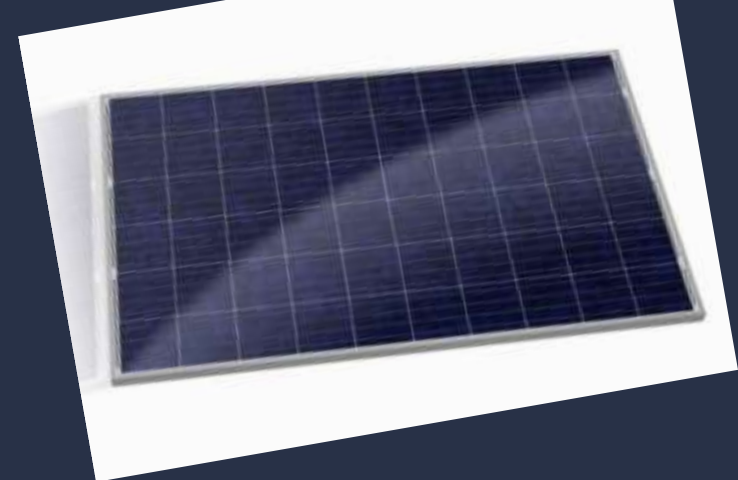


- Europe a lancé l'installation de masse suivi par l'Asie (Chine)
- 125-130 GW in 2019 (700 km²)
- 2-3 TW installed by 2030 ?



Installation PV par région 2010-2018

Au cœur du PV: le module photovoltaïque



Courbe d'apprentissage:

En 30 ans, le Watt de module

A baissé d'un facteur 30 à 50

(0.2-0.3 CHF/Watt)

CH: 1 w → 1 kWh

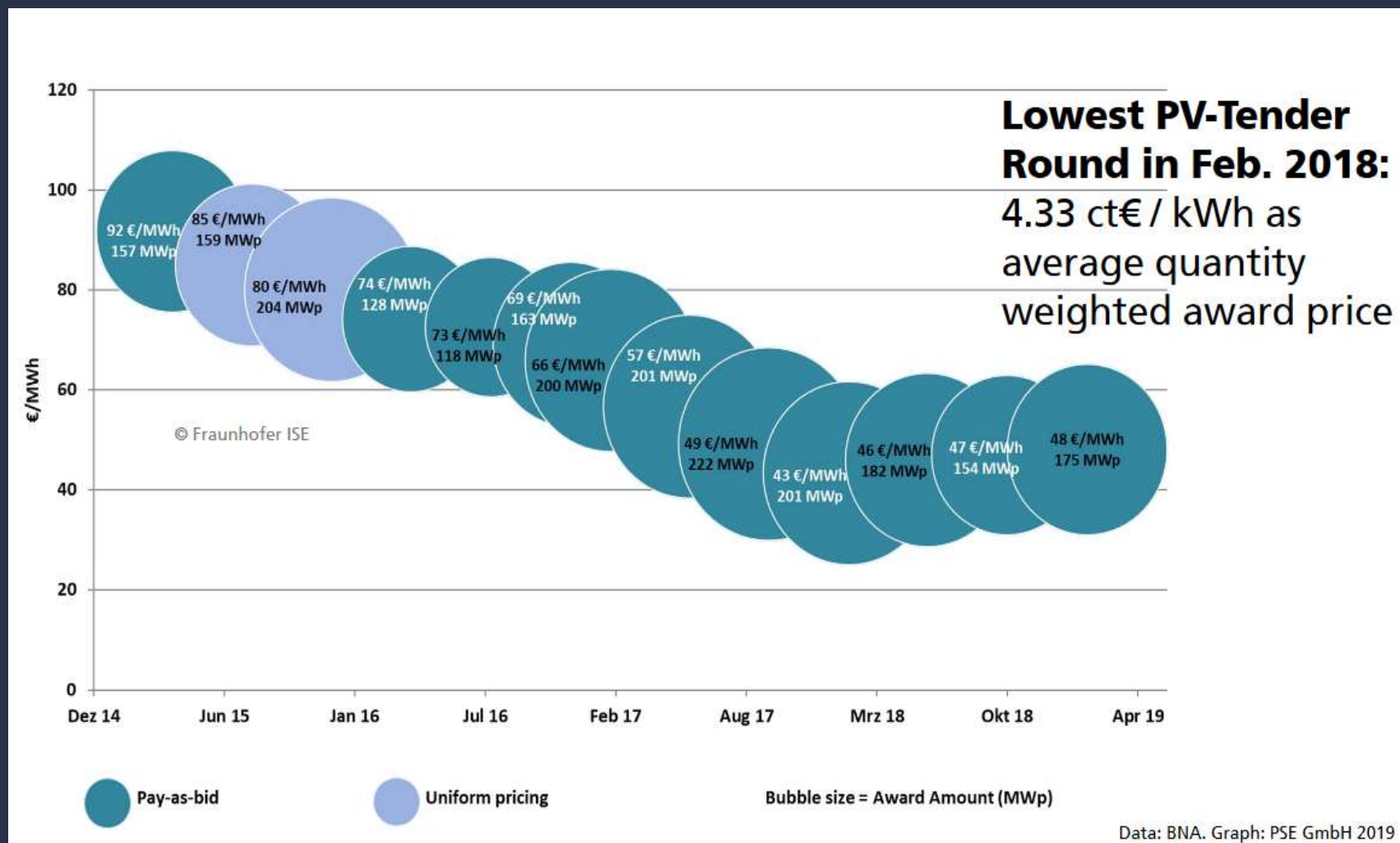
5

- 2020: 1 m² d'un module à 20% → 44 CHF → 6000 kWh en Suisse sur 30 ans
- Le module est meilleur d'un facteur 15-20 en coût d'importation que le pétrole**

La révolution solaire en cours: grands parcs solaires

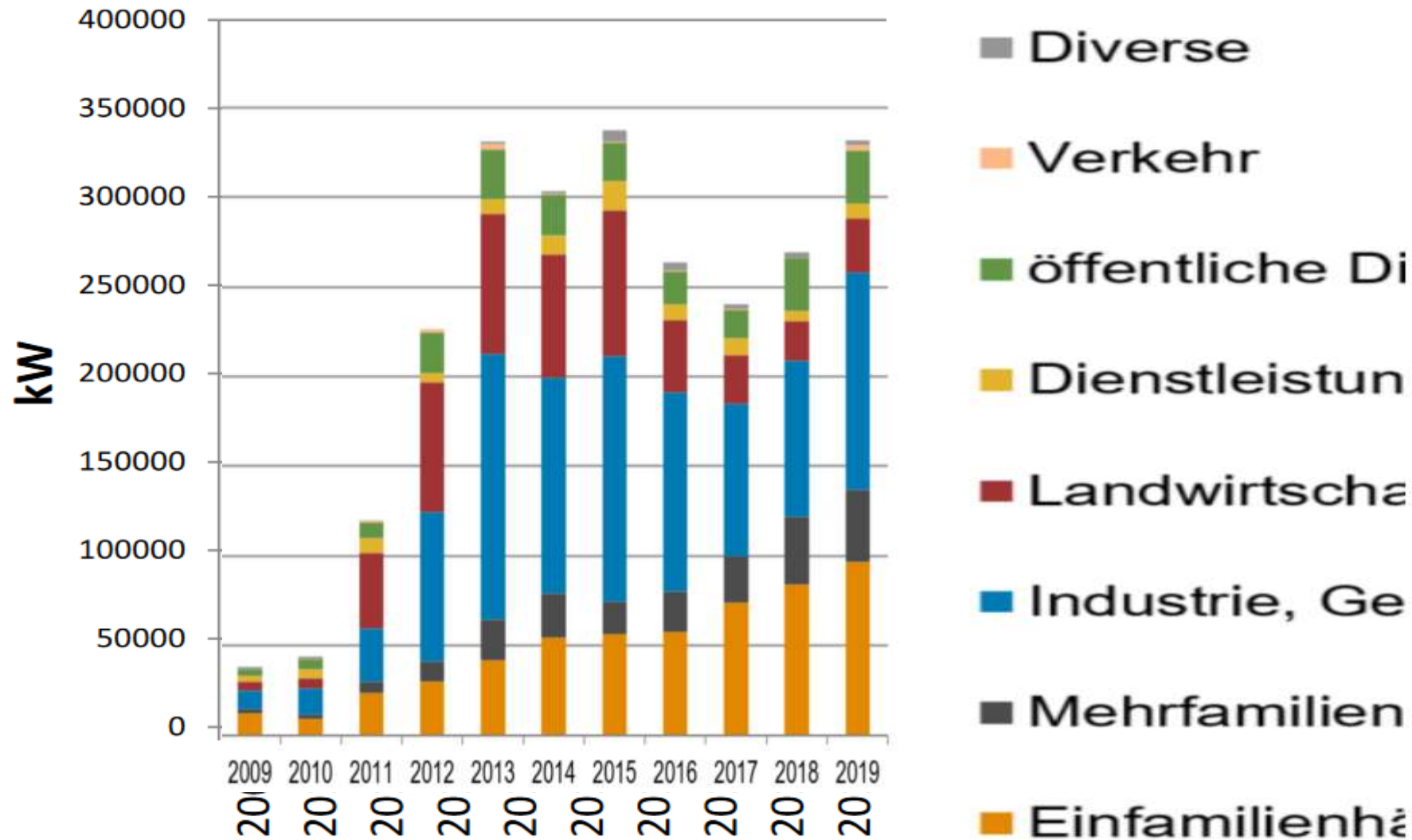
PV-Tender en Allemagne: attribution moyenne des contrats

- Allemagne: moyenne 4.6€cts/kWh, meilleure 3.8€cst/kWh
- Régions ensoleillées ~ 1.5-3 cts/kWh !
- Dans de nombreux pays du monde le PV est la source d'électricité la moins chère

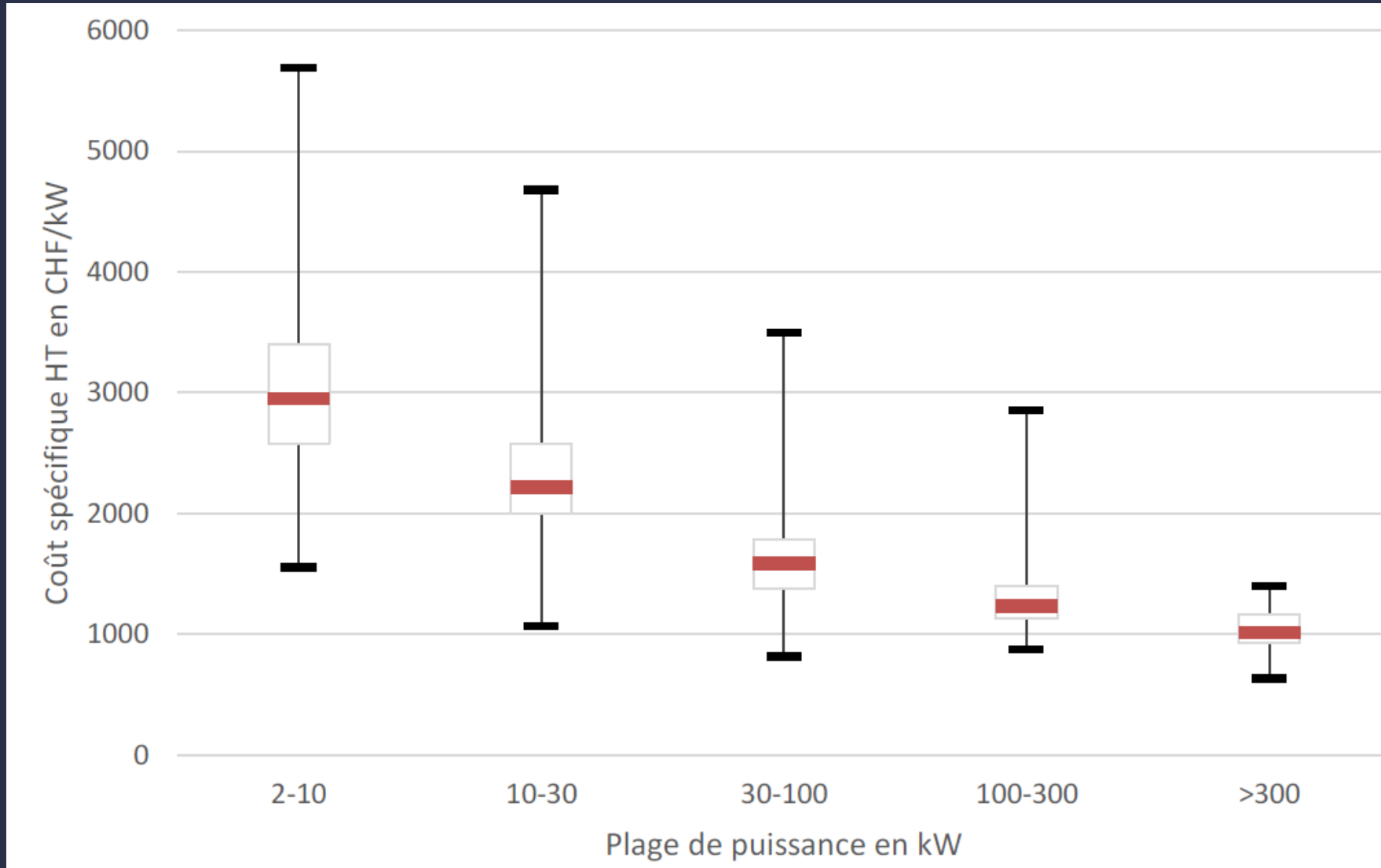


Data: BNA. Graph: PSE GmbH 2019

Mid 2020: 2.5 GW installed, 4.1 % of annual CH electricity consumption



Coût des systèmes PV en Suisse, 2018



Courant solaire
6 à 20 cts/kWh
En Suisse

>300 kW @ 1 CHF/W

30 cts/W panel

7 cts/W inverter

8 cts/W mounting
structure

15 cts/W installation

40 cts/planning/admin
/margin

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Installation Solar Planet, chez MPS par Soleol SA

~ 1 CHF invest $\rightarrow$ 1 kWh/an $\rightarrow$ 6- 10 cts/kWh



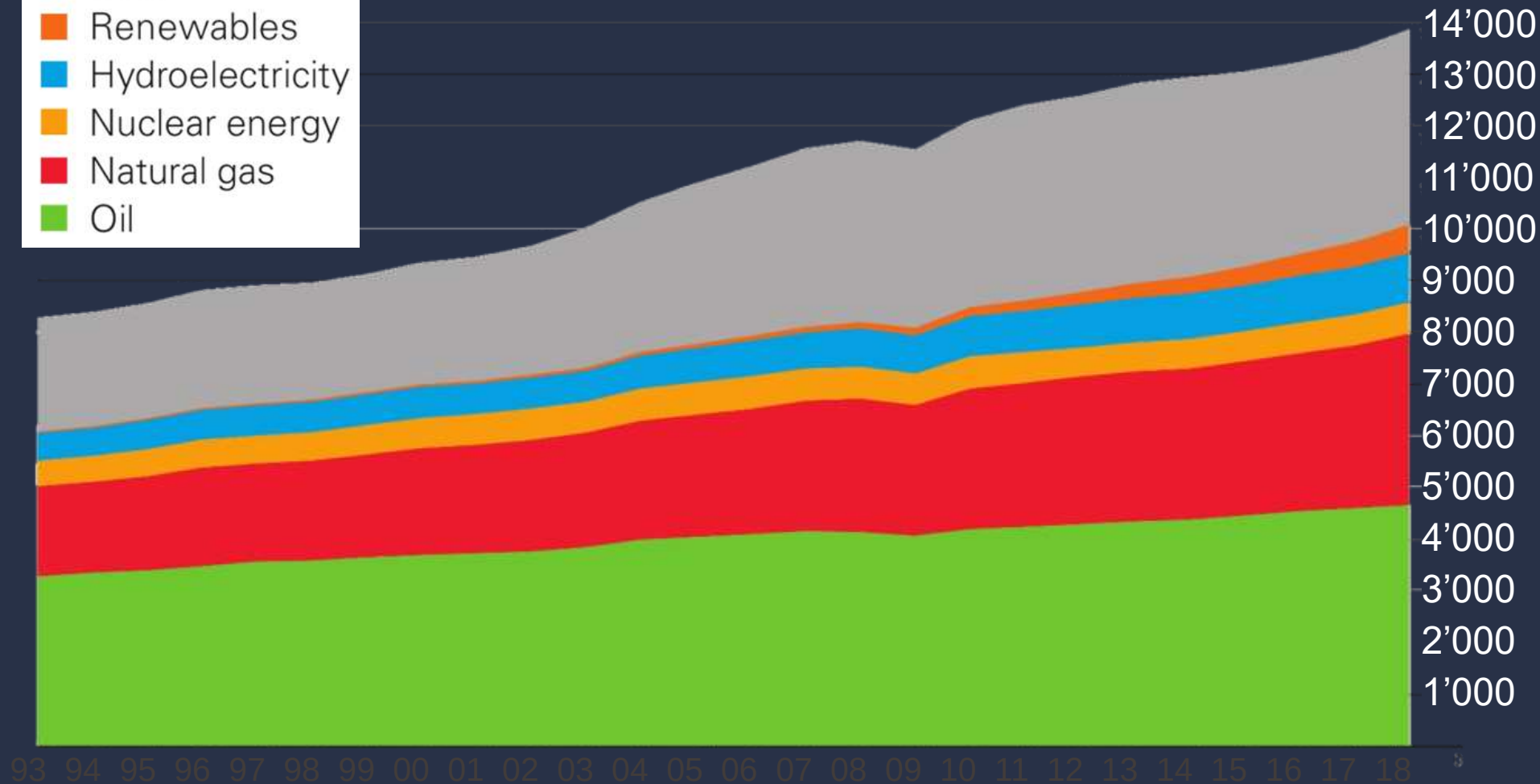
Toiture solaire par Solstis,
2-3 CHF/W 10-15 cts/kWh

Current status of world energy consumption in 2018

reminder : electricity from hydro, solar and nuclear divided by 0.38 to come to primary energy value for BP report



World consumption
MTOE



162'000
TWh

- 2-3% Annual Increase (except 08-09)
- Fossil for 80%
- Coal for 27%

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Dip in 2020 ??

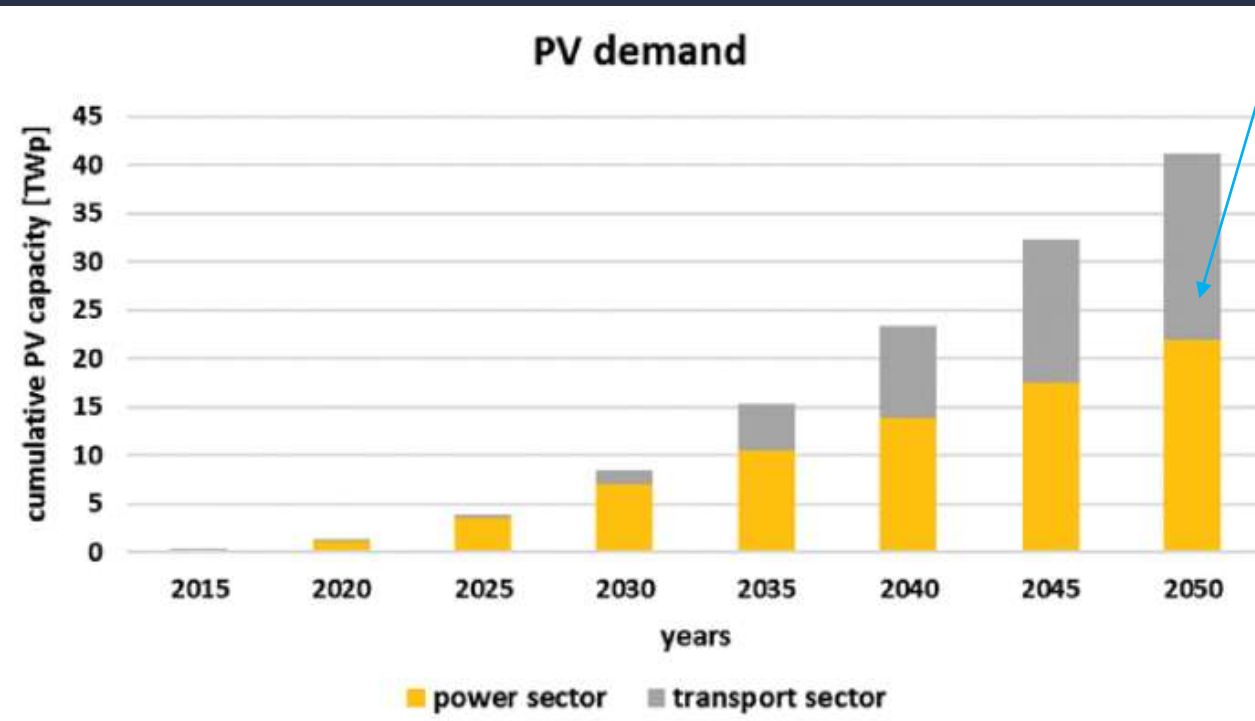
Decarbonizing the power sector and transitioning electricity

* C. Breyer, et al. *Prog Photovolt Res Appl.* 2018

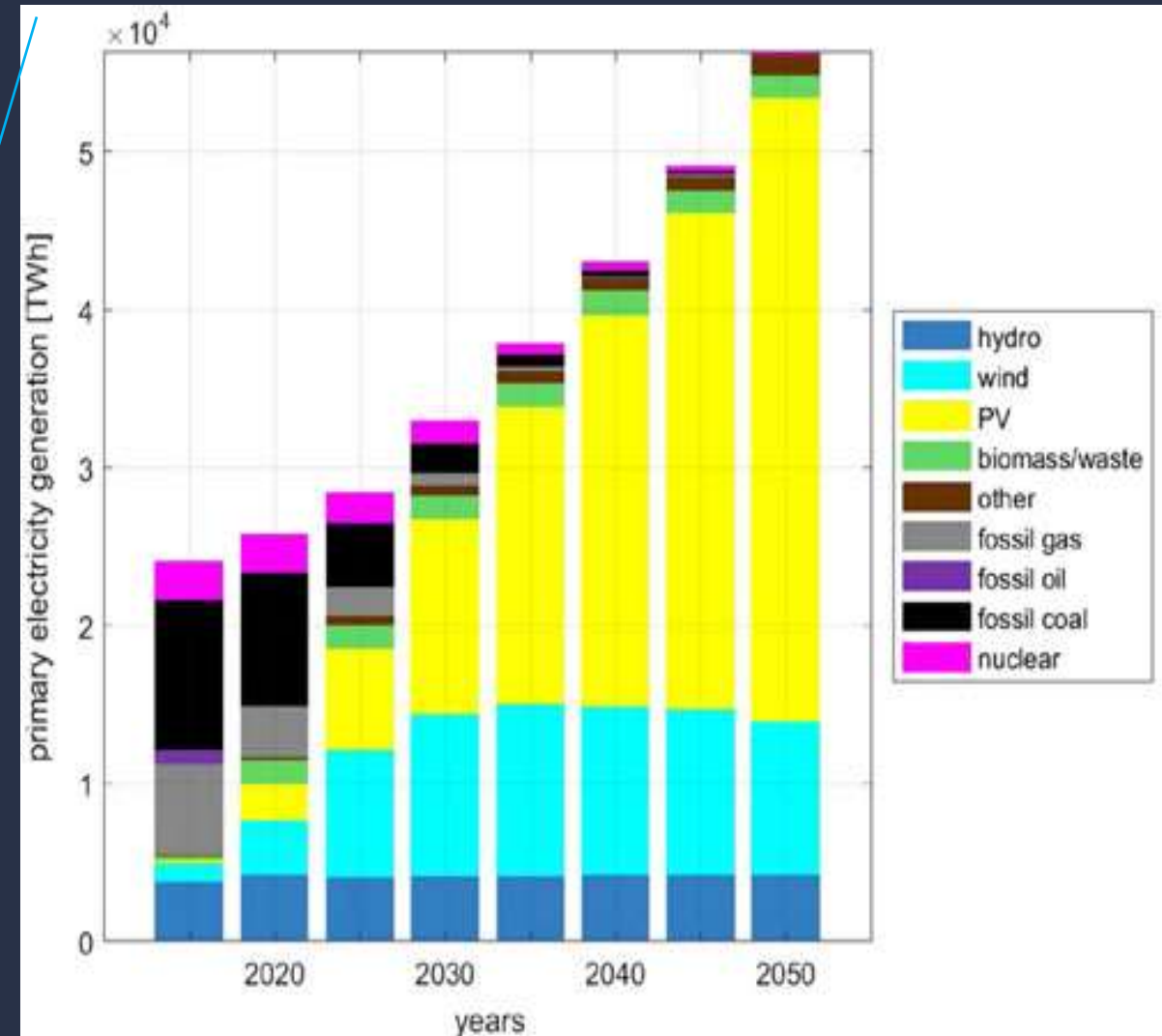
** C. Breyer et al. *IEEE* 2018

25-40 TWp of PV**!

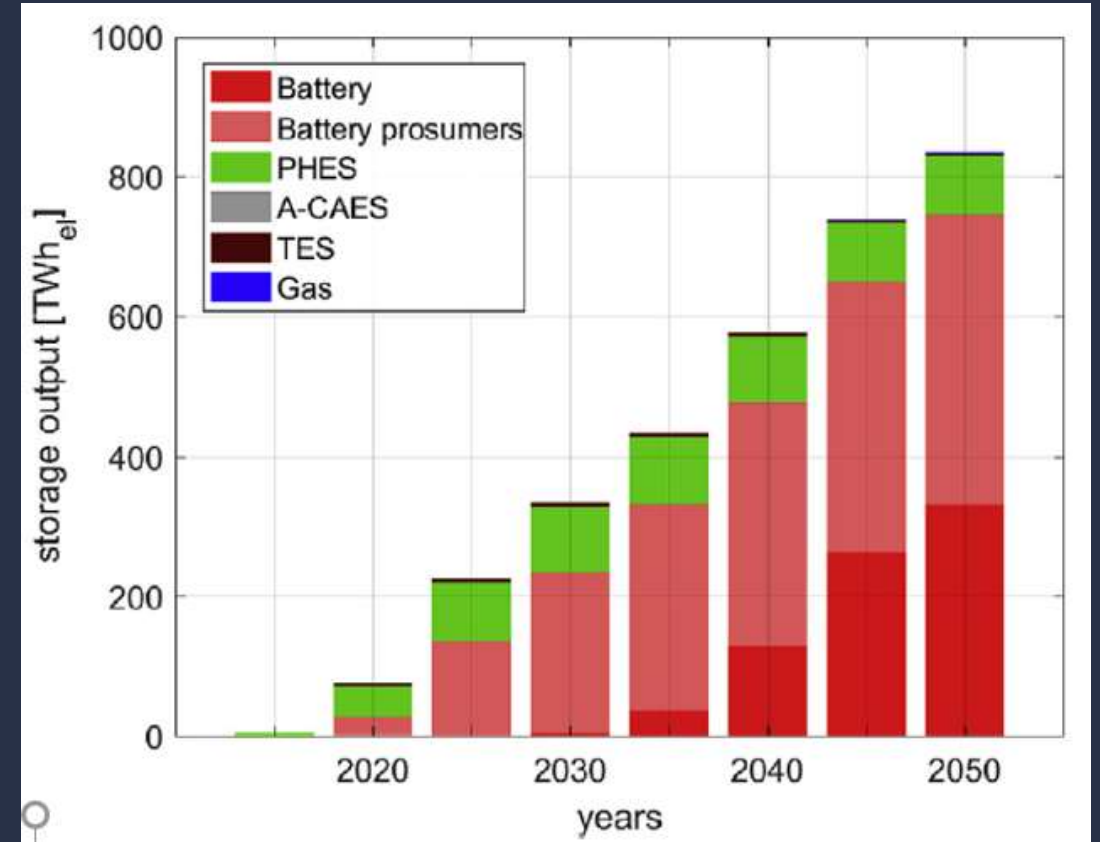
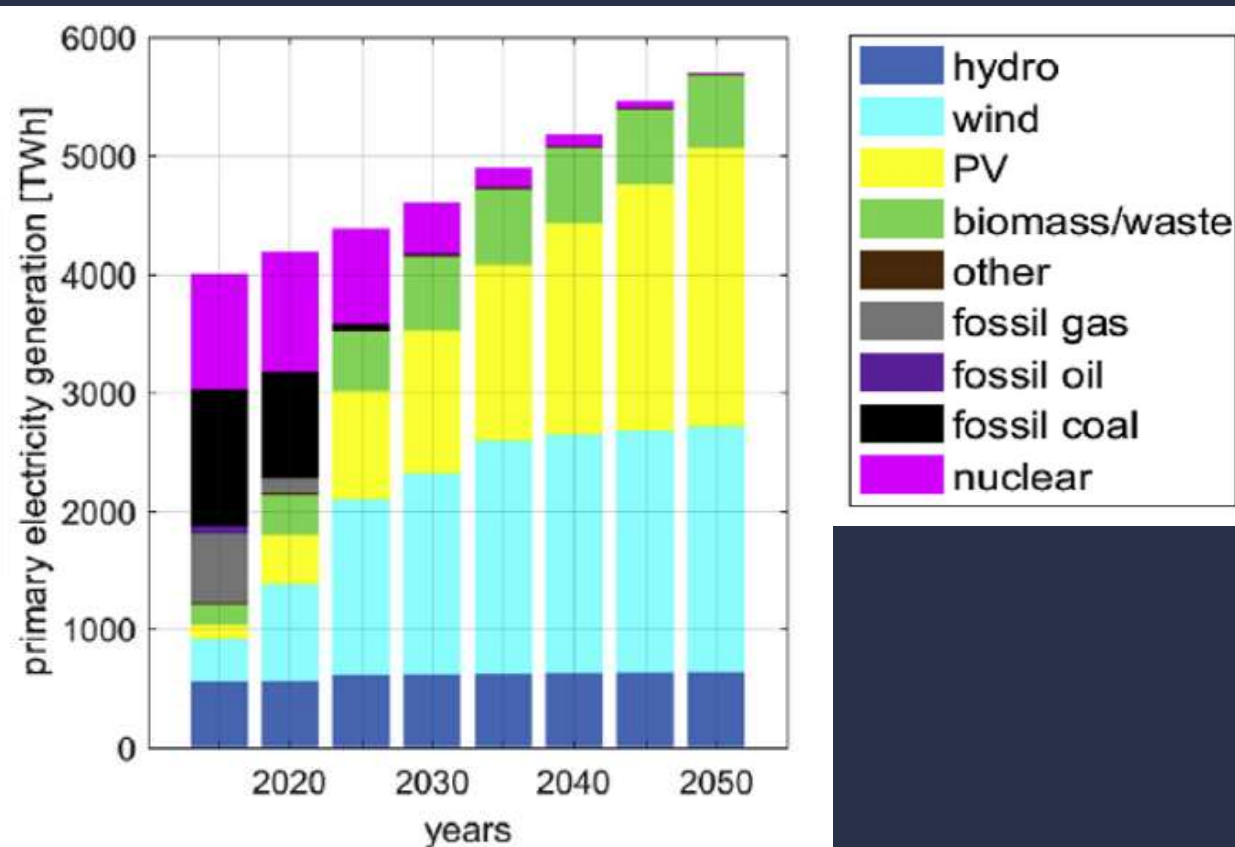
→ electricity cost decrease from 70 to 55 Euro/MWh



On example of what it could be according to Breyer and al* Assuming 2% annual growth of energy demand and fully decarbonized transport system



A short look at Europe (in a area connected scenario)



Michael Child, C. Breyer, et al. Renewable Energy 139 (2019) 80-101



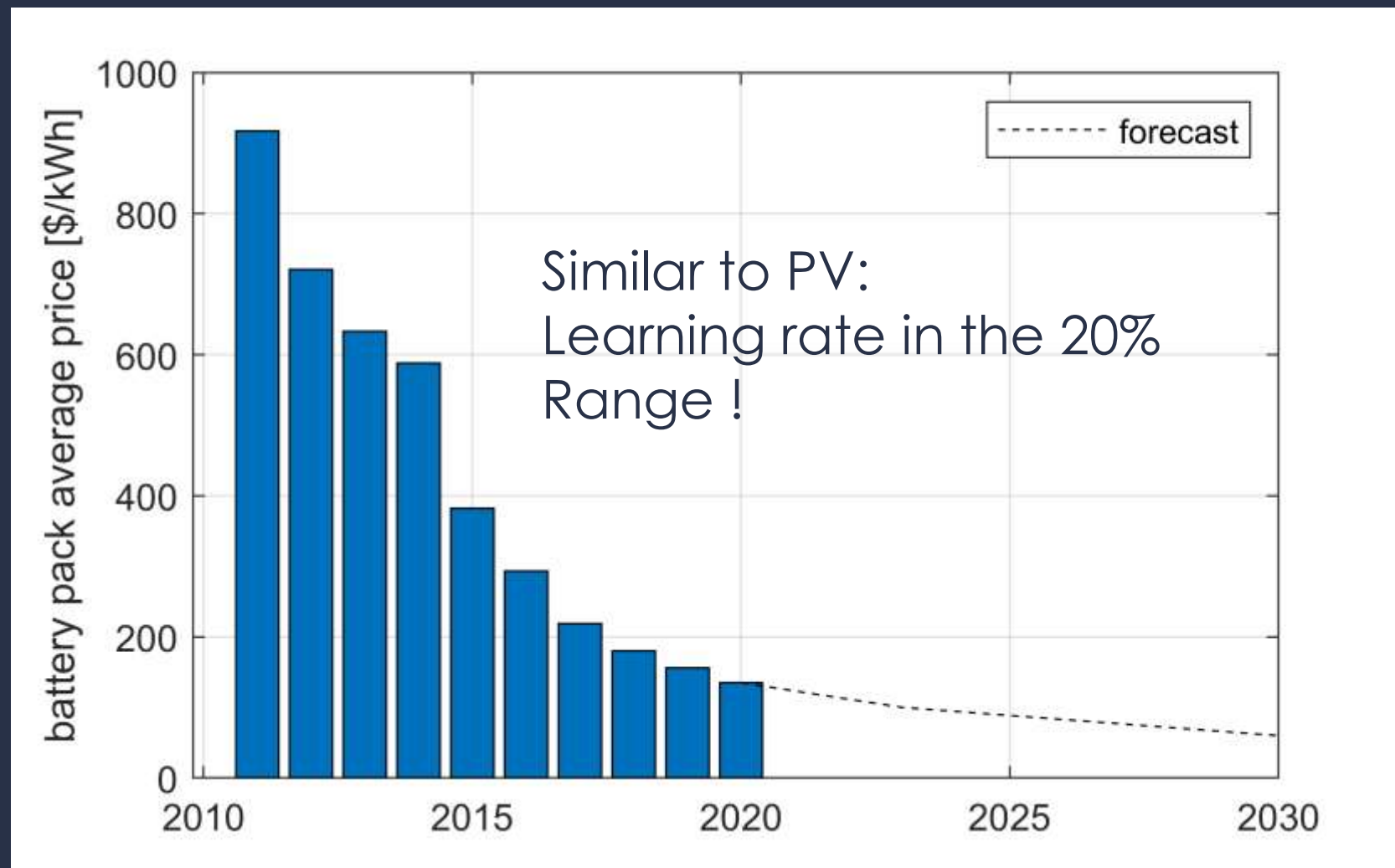
Global LCOE

Lower by 20% than today !!!

Battery storage and pumped hydro necessary to balance the grid

Electricity storage - lithium ion batteries

Evolution of the battery pack price from 2011 to 2020



- From 135 \$/kWh in 2020 to 60\$/kWh in 2025-2030 ?
- Cost reduction depends on market growth speed. Likely much faster
- Batteries will become much cheaper, thanks to volume effects ! 13
- Prices for li-ion ~600-1000 cycles.
- More cycles more expensive but synergy with car batteries

- **Green hydrogen from CH or abroad**

Large PV powerplant at 0.3-0.4 cts/W in 2030
(today's best at 0.5 cts/W) → electricity price
down to 1.1-1.3 cts/kWh

- Progress in Electrolysers (alkaline or others) → < 500\$/kW with potential cost < 250\$/kW at full power plants level

Potential for hydrogen at 1-1.5\$/kg.

International trade of hydrogen



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H2 as a support to energy management, and industrial process

- Or replacement in gas powerplants
- In distribution network



Hydrospider and Alpiq: → 2MW electrolyser for H2 for trucks, in Gösgen

Sustainable manufacturing



In a number of cases, creative companies have figured out sustainable business cases. Swedish power company Vattenfall has calculated that producing a €20,000 car from CO2-free steel (using green hydrogen) rather than regular steel would add just €200 to the price. That suggests premium markets could be developed for consumers willing to pay 1% to 3% more for products manufactured using green hydrogen.

Si l'humanité est sérieuse à propos de la décarbonisation



~~Industrie Pétrole/Charbon/Gaz
Lobbies, media et politiciens qui y
sont rattachés~~



- Augmenter x 10 la production de PV d'ici 2030
 - → 25 TW installés en 2050
→ 30'000 TWh
- (consummation mondiale 2017 d'électricité ~ 22'000 TWh)

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**Nous sommes juste au début de
l'ère solaire ...**

Que faudrait-il pour vraiment décarboniser la Suisse ?

50 GW en 2050?

- Voitures électriques (+ 10-15% hydrogène)
- Pompes à chaleur/chauffage à distance
- Efficacité (isolation, pompes, industrielles,...)
- Ecretage de 15 à 20% du PV
- Soit 16% d'émission CO₂ (9 TWh) pour électricité hivernale (gas)
- ou stockage H₂ ou CH₄ (power-to-gas), ou importation d'électricité éolienne du nord de l'europe (si c'est possible)...



The second reason why you need to shift to renewables

Importation of 50 GW of solar pannels

=

(30 years of energy) → 12.5 Milliards de CHF

2 years of oil import product

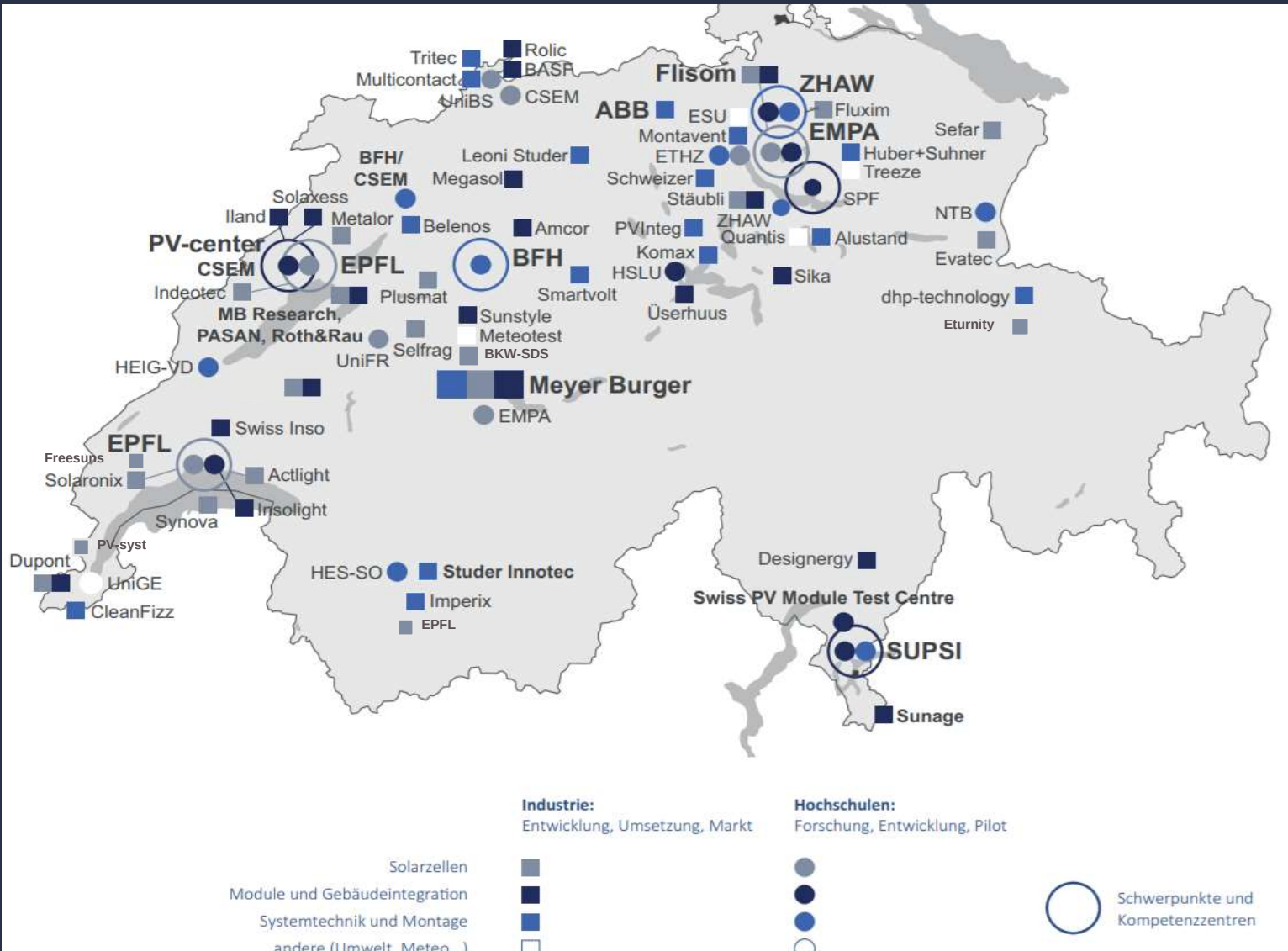


Unique « solar » landscape



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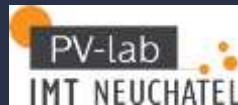
- Academics and research: CSEM, EPFL, EMPA
- Univ. of Applied-science: ZHAW, SUSPI, BFH, HSLU, SPF,...
- > 50 Industries and Start-up
- >> 200 installers and engineering offices
- A perfect country for mass implementation of fluctuating renewables



R&D in photovoltaics and energy systems in Neuchâtel



EPFL



- EPFL
IMT/PV-Lab (1984)
 - Fundamental research
 - Advanced devices



csem PV-Center

- CSEM, RTO
PV/Center (since 2013)
 - Focus on tech. transfer
 - Dev. for industry, innovation

Production and
commercialization



Industrial partners
Spin-off, Start-ups

In contracts with
over 40 companies

**Technology
infra-
structure
Platforms**

Thin film
Coating &
lasering

Cells Pilot
lines

Modules
R&D lines

Polymers
counpounding/
extrusion

Testing and
reliability

(micro-) grid
/storage testing

with Supsi

ESREC with BFH

Metrology and characterization

Data management

Over 2000 m² of
Infrastructure
completed with

- UV chambers, thermal cycling, Damp heat
- Battery env. Testing
- Battery EIS



2000 m²



RESEARCH



&



PILOTING



CONTRACTS WITH OVER



40 COMPANIES



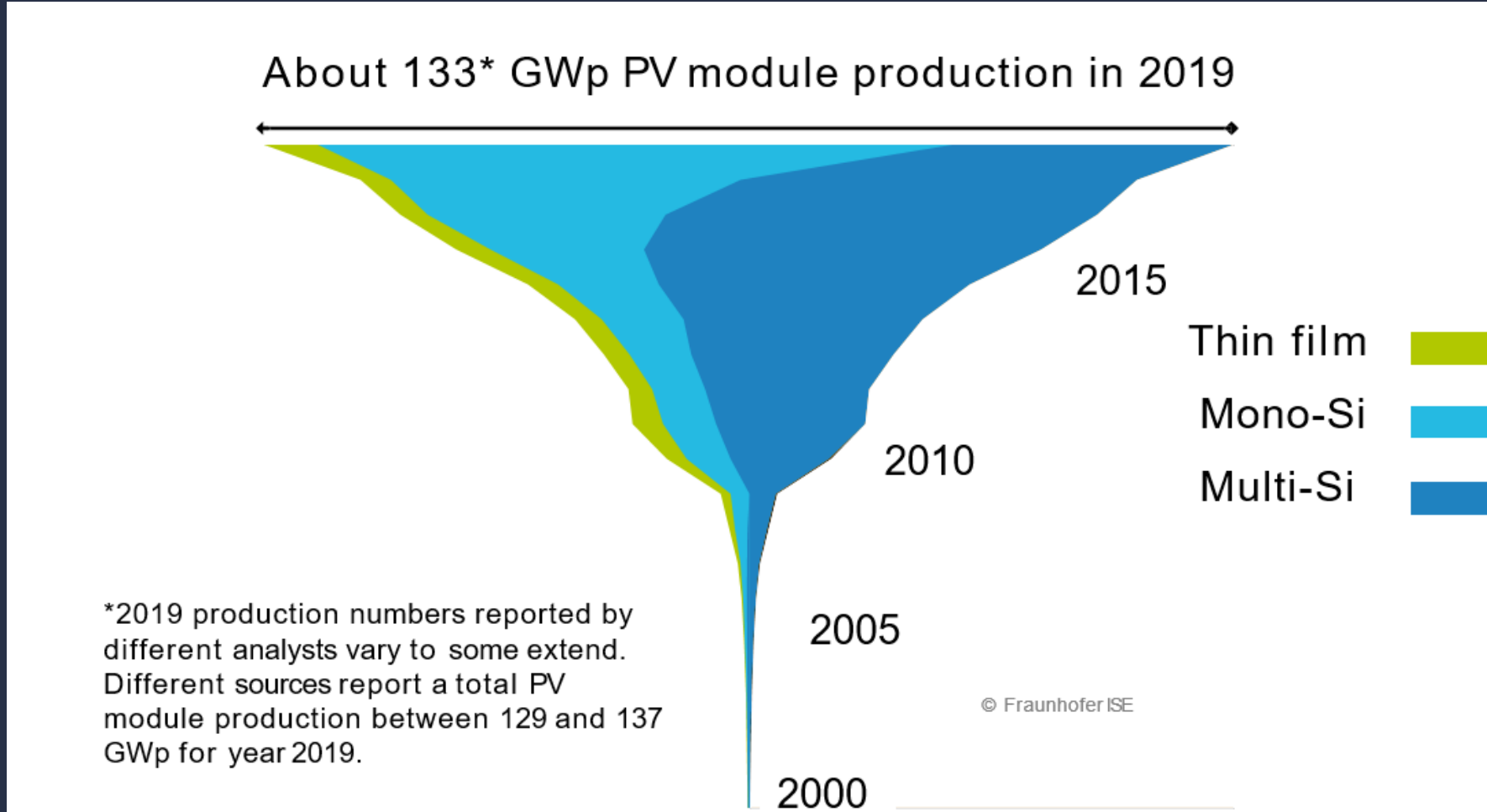
ALONG



THE CHAIN



Market technology evolution

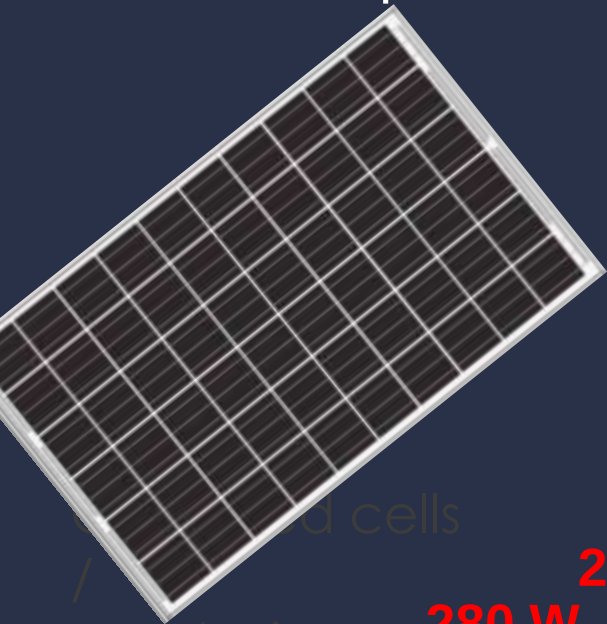


C-Si takes it all.

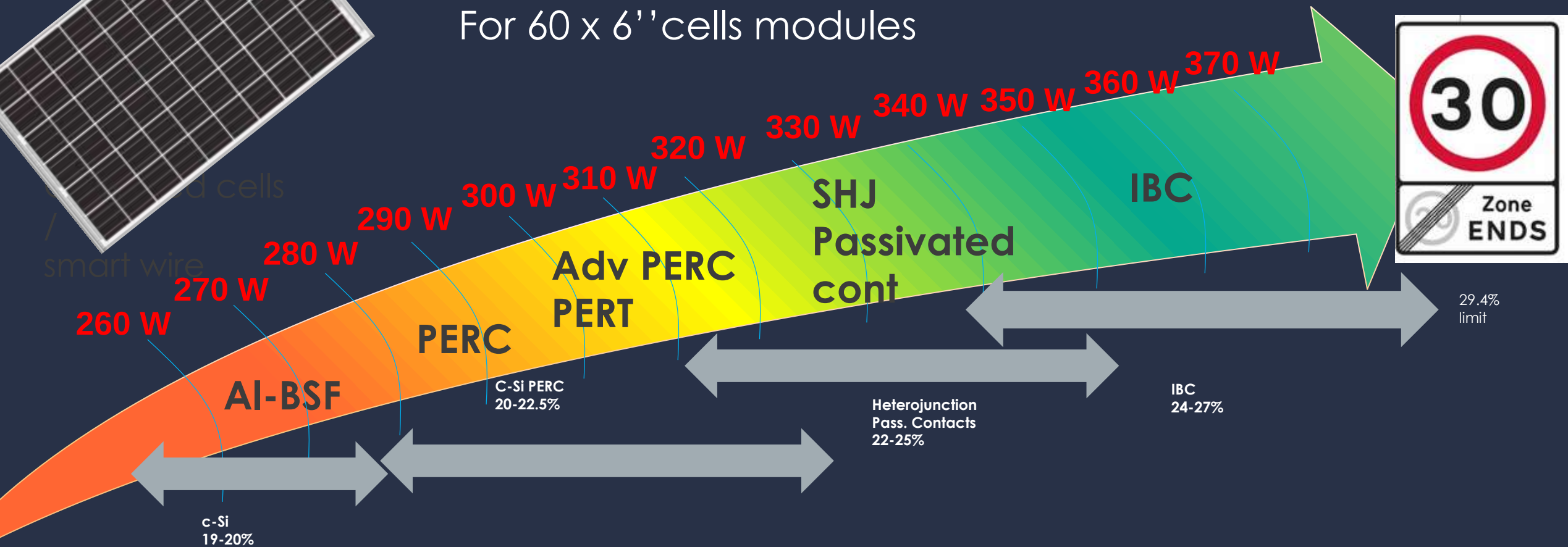
Only First Solar resists with CdTe modules and sufficient efficiency (18% modules)

Powerpure

Permanent (sometimes invisible) improvements to technology

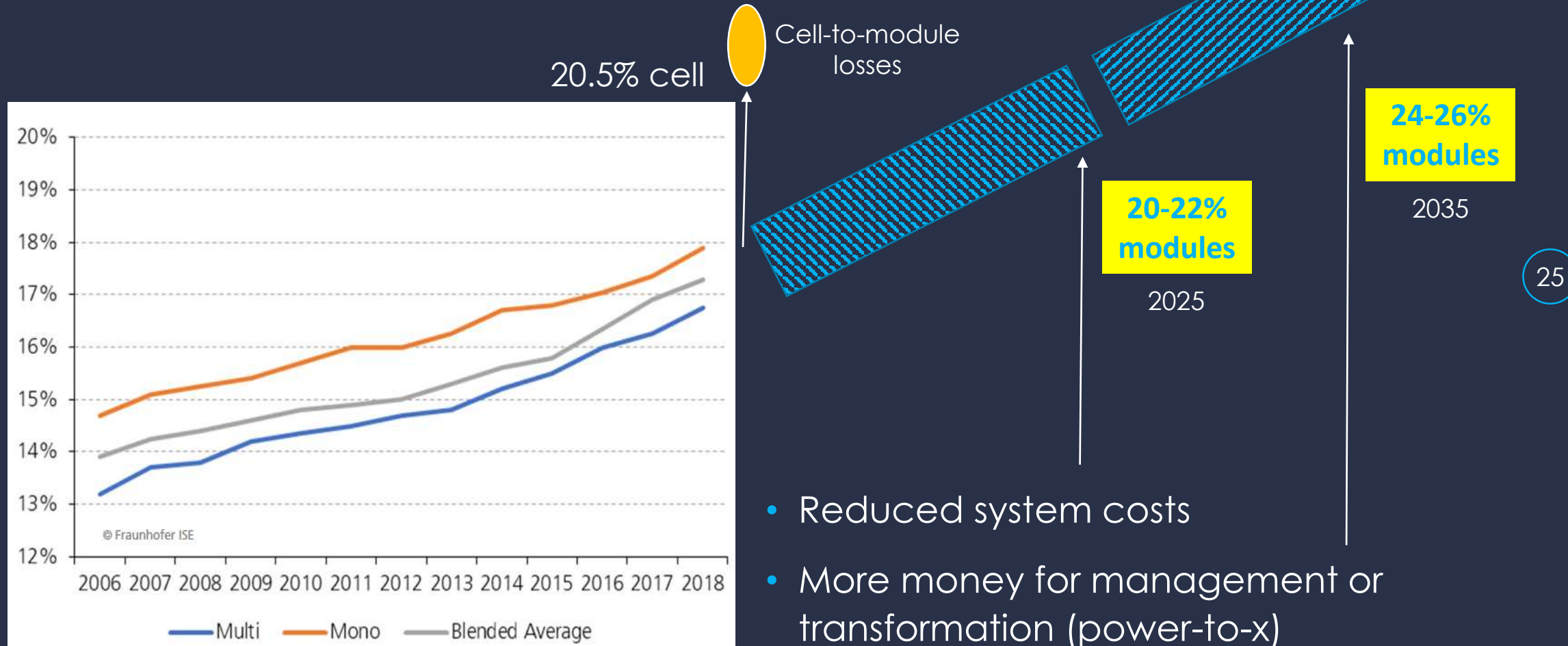


For 60 x 6'' cells modules



PV module efficiency improvement: a necessary trend !

0.4% annual module absolute efficiency improvement

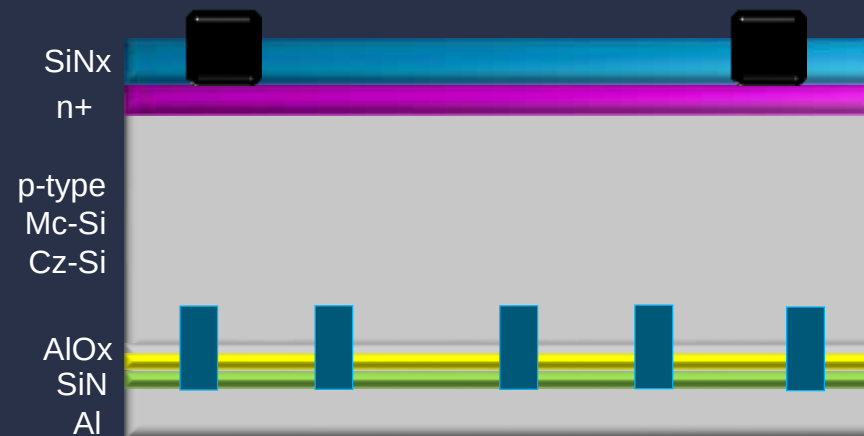


- Reduced system costs
- More money for management or transformation (power-to-x)

Data source: HIS Markit 2019

Powerpure

Al-BSF cells is being replaced by PERC and other kinds of cells



PERC: passivated emitter and rear cell
local front and rear contact

20%  PERC
+ 1-2% 22%
Cell efficiency

**Major Market-
trend**

Switch to monocrystalline

Al-BSF

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Powerpure: the change in module design

The 7 trends which will make PV even cheaper, and greener



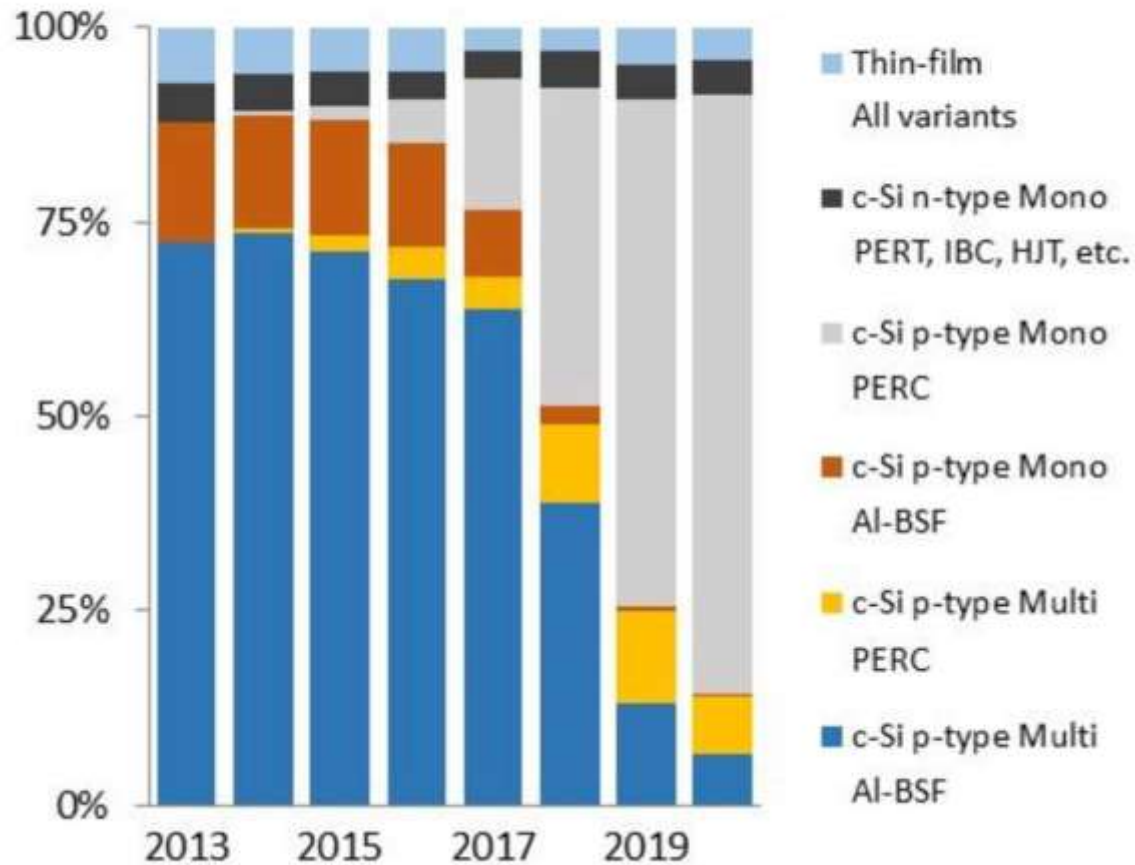
- More busbars to save on the cost of screen-printed Ag lines
- $\frac{1}{2}$ cell or shingled cells to gain space and reduce loss in ribbons



100 mg less of Ag per solar cell, 0.5% more power

A drastic change in the PV industry

PV Technology Shares by Production



- The market is shifting very quickly to monocrystalline silicon
(progress in crystal pulling and sawing, need for quality for high eff.)
- PERC solar cells are taking 95% of the market
- TOPCON, Heterojunction as high efficiency products pulling (extending) PERC ?
- But new products with new challenges ... (e.g. degradation modes)

- Mines et matériaux
- 95% du marché panneaux en Silicium, 2^{ème} matériaux le plus abondant (pris du quartz ou du sable)
- Pour 1 m² (→ 6000-9000 kWh sur 30 ans)
- 1.5 g d'argent par m² de panneau, 1 kilo de polymères/plastic, 200 g de Cu
- Pas de problème d'approvisionnement, Ag et Cu peuvent être réduit



Durabilité du photovoltaïque

- Energie grise: une réduction forte grâce aux progrès industriels.

Il y a 20 ans, il fallait 17 g de silicium pour faire 1 W de cellule

Et il fallait 300kWh/kg d'énergie pour mettre le silicium en forme, soit 5kWh/W →

→ Temps de retour de l'énergie de l'ordre de 5 ans en Suisse.



1^{ère} amélioration majeure

- La purification et cristallisation du silicium : le procédé Siemens

Recrystallisation de 10 tonnes à la fois, surfaces réfléchissantes, seed tubulaires...

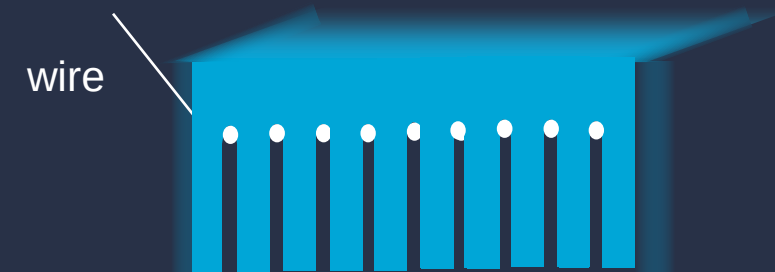
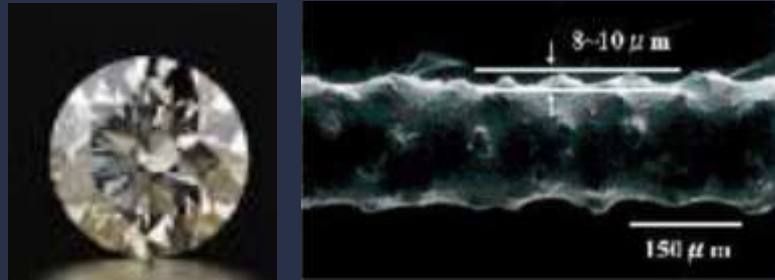
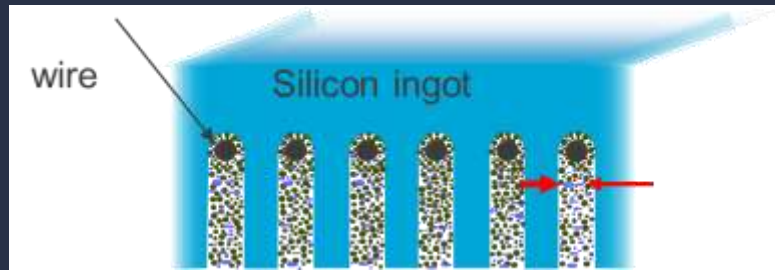
Plus que 45 kWh/kg contre 200 kWh/kg en 2000 !!!



Source: Silicon Products Bitterfeld GmbH & Co. KG (SPB)

Powerpure

The 7 trends which will make PV even cheaper, and greener



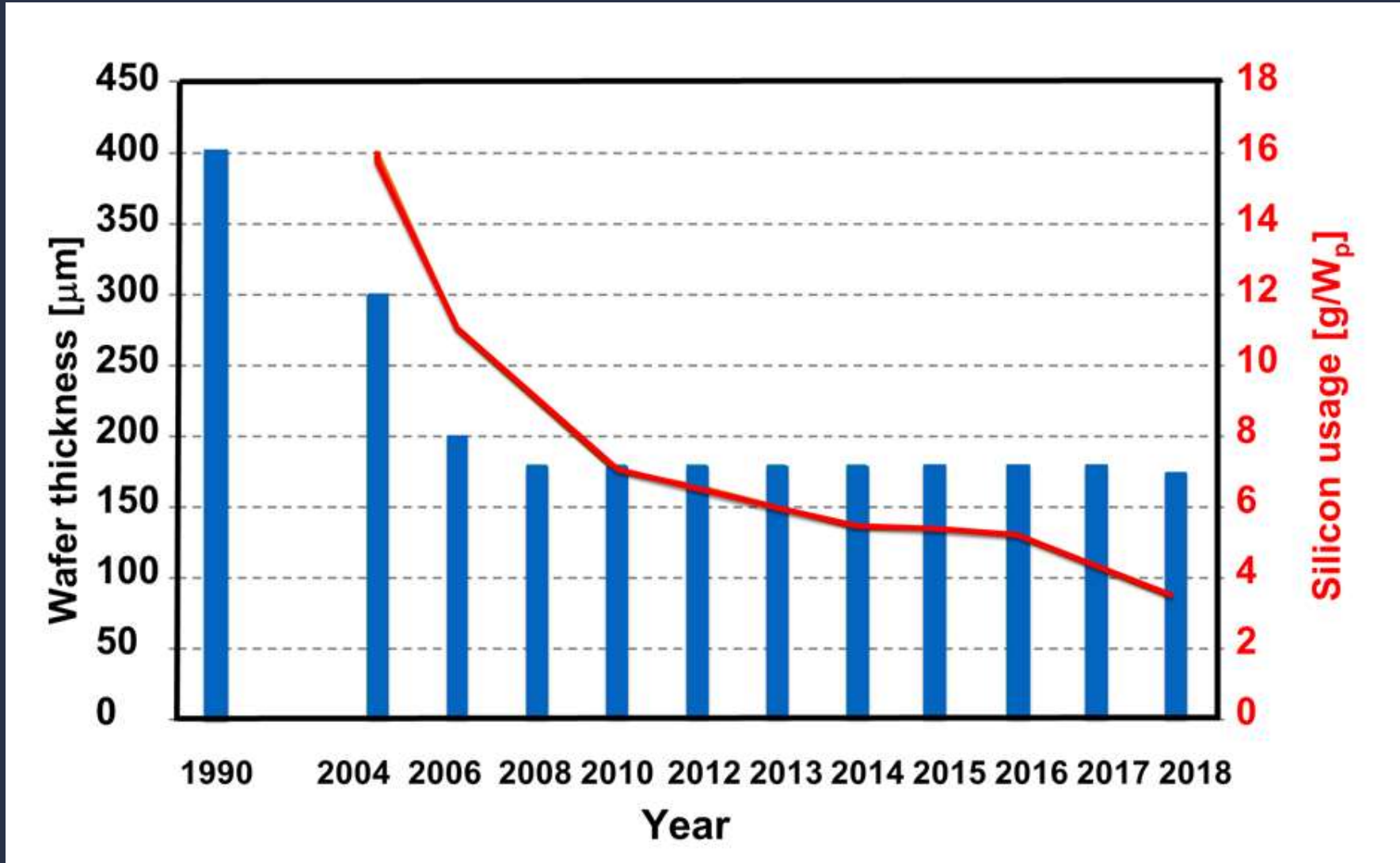
- Yesterday, multi-wire sawing, SiC particles loose 200 microns
- Today, diamond wire for mono loose 60 microns
- → 60 % more wafers than 5 years ago !

3.5-4 g of Si/Wp
Silicon 12-15 CHF/m2



E-Payback-time down to <<1 year !

Silicon usage per watt



Improved processes

Sawing

Efficiency



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From 17 to 3.5 g/W
in 20 years,

With low grey energy

Powerpure

Trends which will make PV even cheaper, and greener



- 1-axis tracking
- + 20-30% energy, at +15-20% initial system costs + maintenance

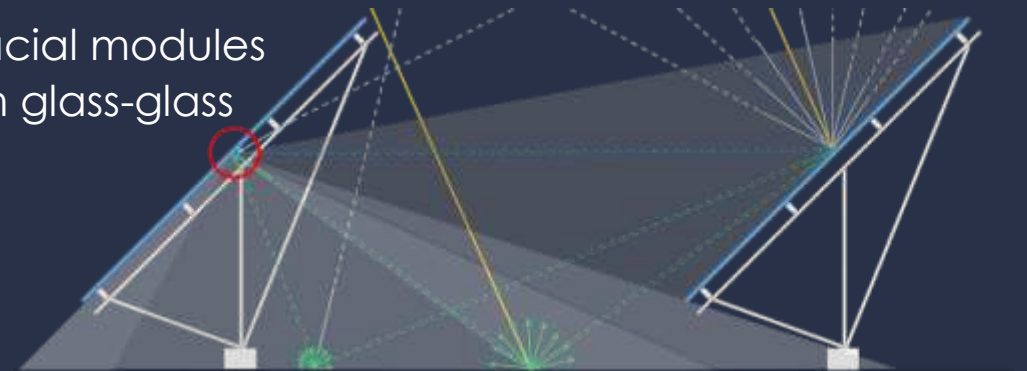
5-10% LCOE reduction

- System voltage $\rightarrow$ 1500 V
- 40 modules in series

LCOE reduction



- Bi-facial modules from glass-glass



**$\rightarrow$ 15-25% more energy for «free»,
 $\rightarrow$ Longer lifetime**

Empreinte CO2 d'un module



Les modules Hanwha Q CELLS obtiennent une nouvelle certification en faible empreinte carbone pour les appels d'offres solaires en France

- Empreinte carbone de 300 kg-eq/CO²/kWc atteinte pour les séries de modules Q.PEAK et Q.PEAK DUO.
- Les objectifs ambitieux de la France en matière d'énergie solaire sont fixés par le marché des appels d'offre CREqui favorise

300 g/W: Sur 25 ans, 25 kWh

Pour les meilleures panneaux cristallins: Avec les procédés de fabrication aujourd'hui, c'est → 8-10 gCO₂ par kWh. Contre 400 g/kWh pour centrale au Gas et 900g/kWh pour centrale au charbon

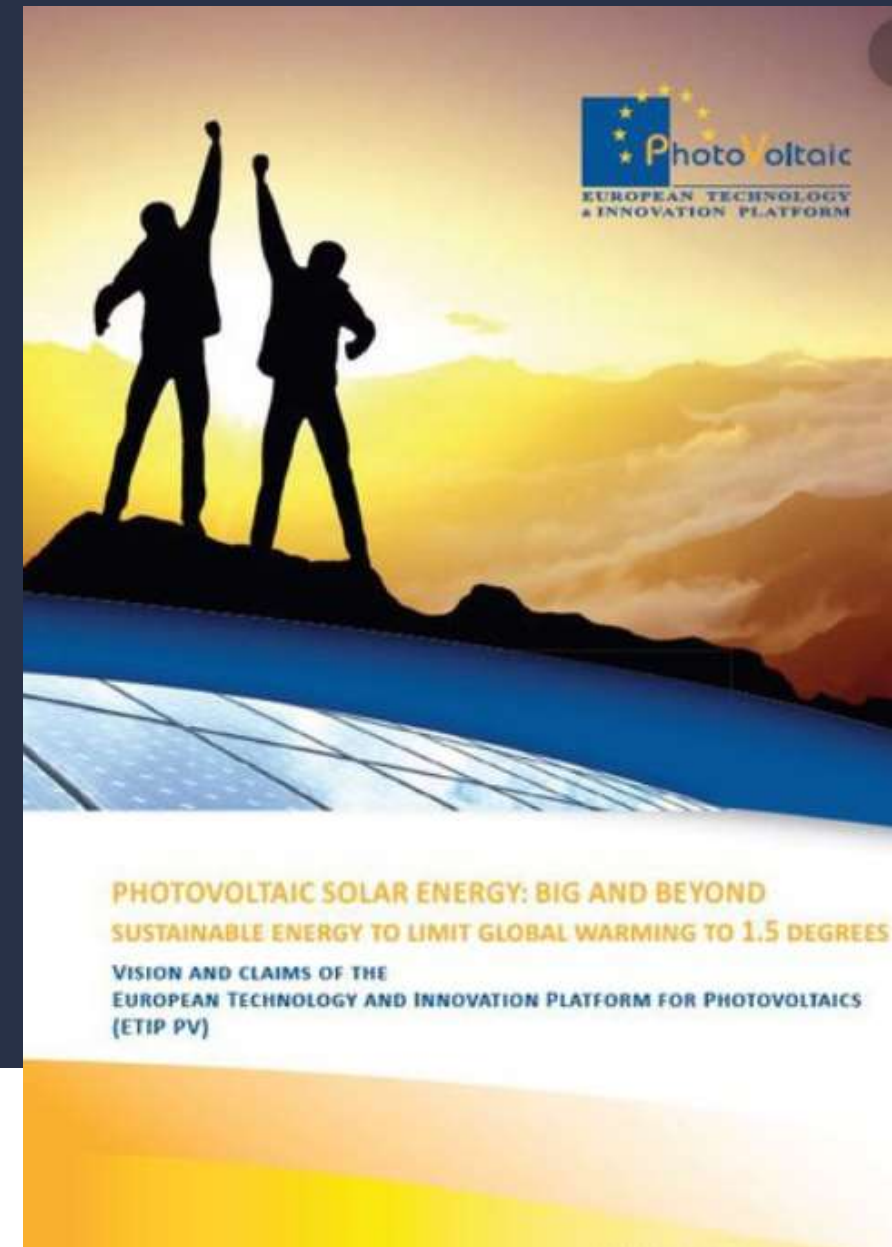
Sustainability world with PV-batteries

- With current good practice,

Producing (30 TW at 300 g/W) PV panels and batteries (2 billionsx 50 kWh at 60 kCO₂/kWh) would lead to $9+6 = 15$ GT CO₂

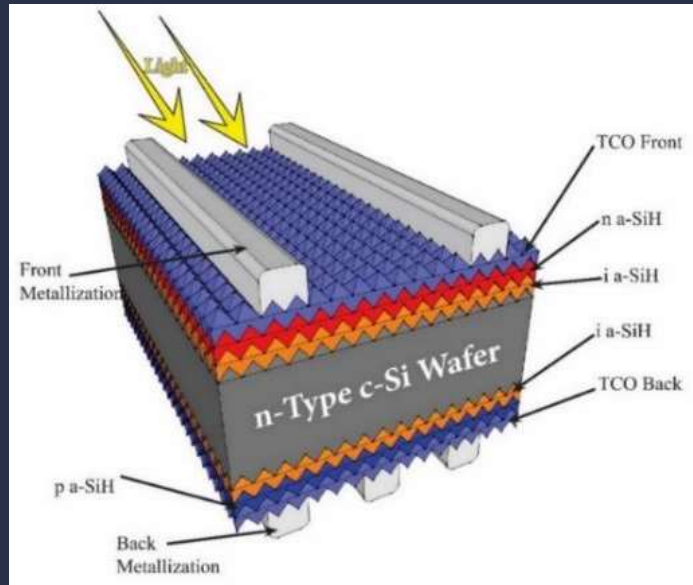
1.5% of what is left in the 2°C scenario

 sons eRecycling



Powerpure development at CSEM/EPFL

Technologies for lowest cost solar electricity beyond PERC SOLAR cells

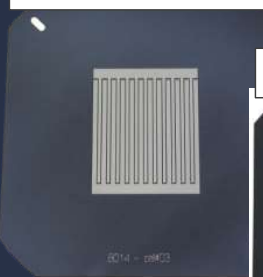


- Passivating contacts devices for PERC upgrade
- Silicon Heterojunction
- Back-contacted solar cells

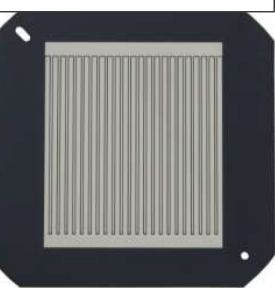


- Few process steps
- High(er) efficiency
- Higher energy yield
- Work with 100 micron wafers
- Bifacial

9-cm² tunnel-IBC



25-cm² tunnel-IBC



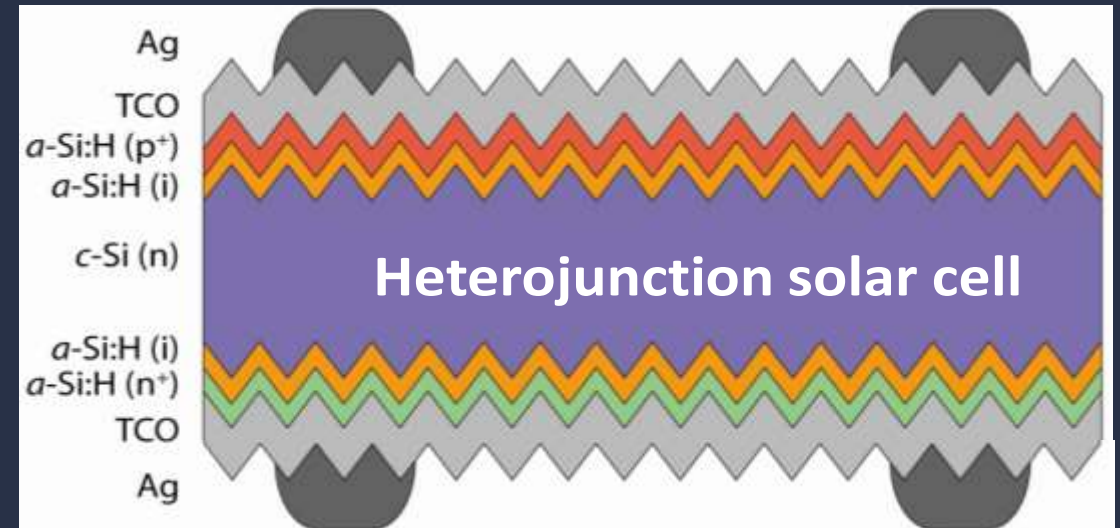
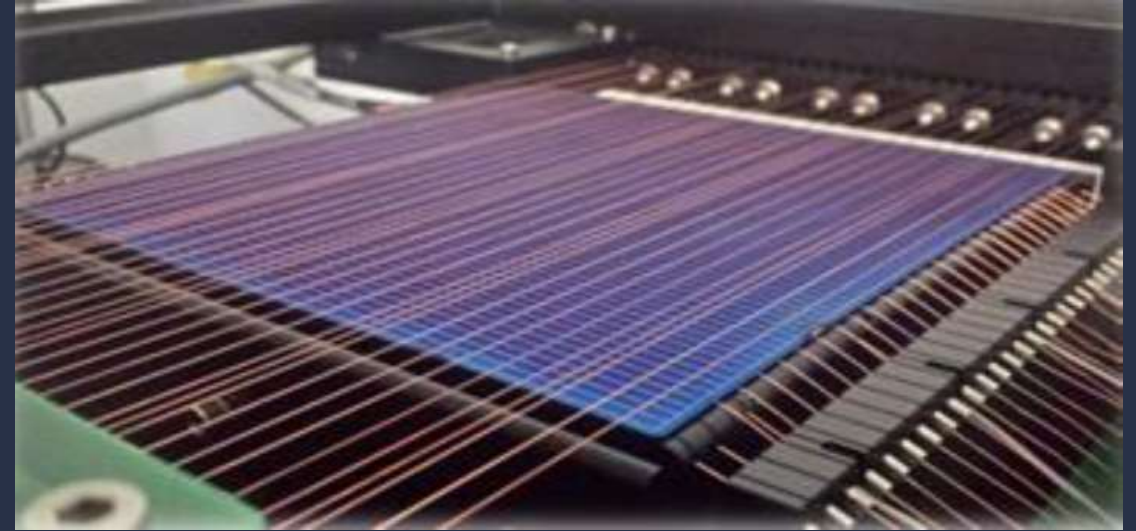
Heterojunction CELL STRUCTURE

- All screen-printed contacts

4 cm² Certified:

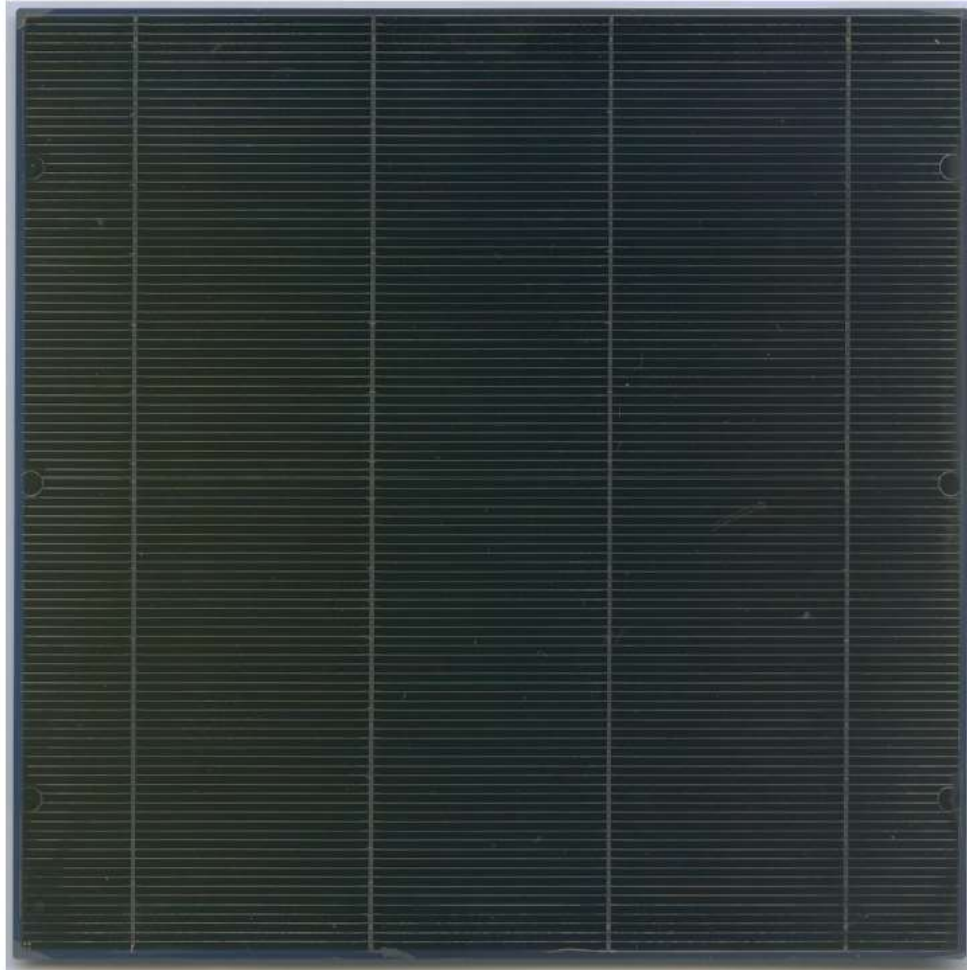
N-type mono : 24.2%

P-type mono: 23.8%

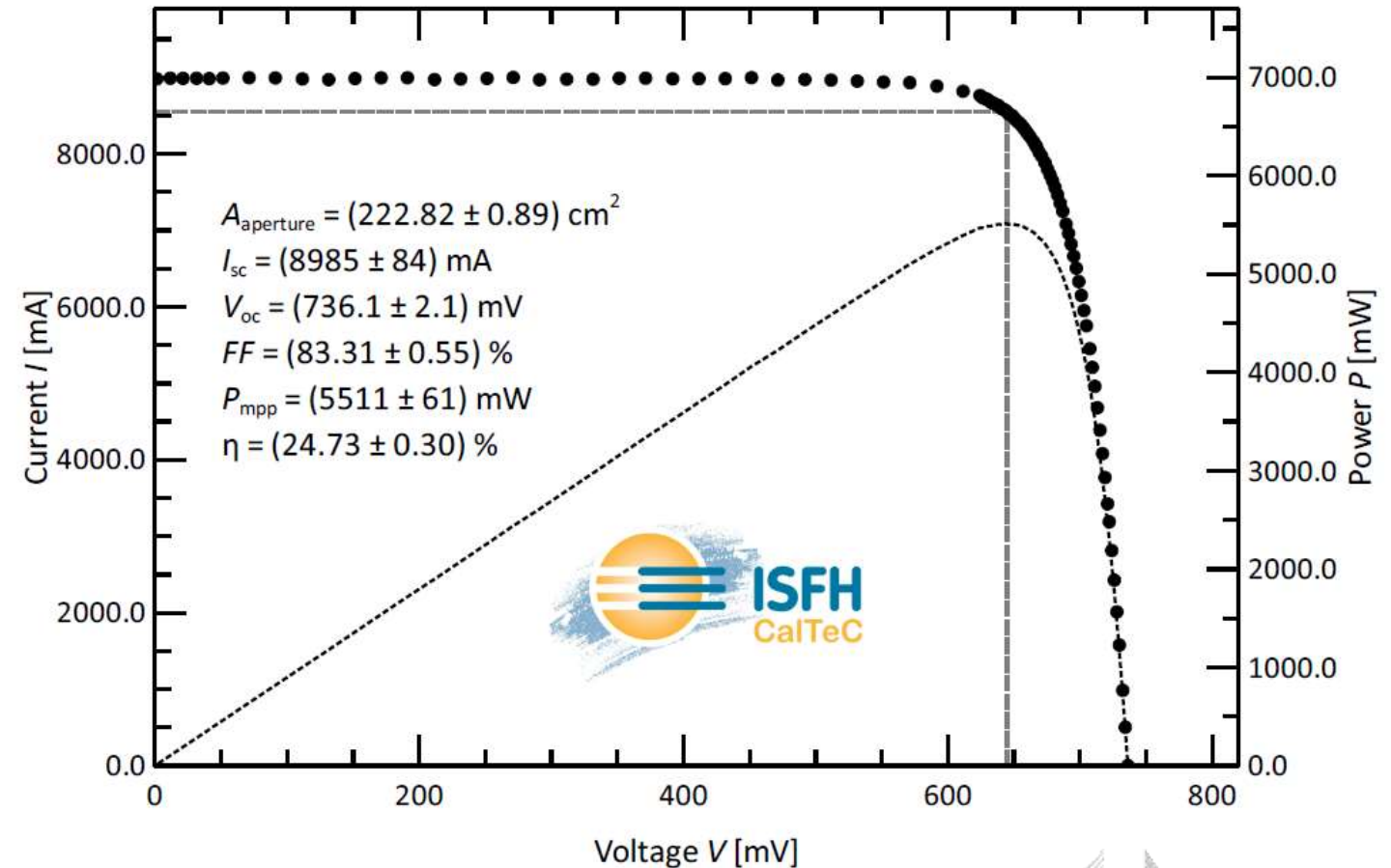


Plated heterojunction cells at 24.73% on 222 cm²

A. Lachowitz et al. CSEM,
Watabe et al. CIE



Last week certification !



From lab, to equipment maker, to production lines

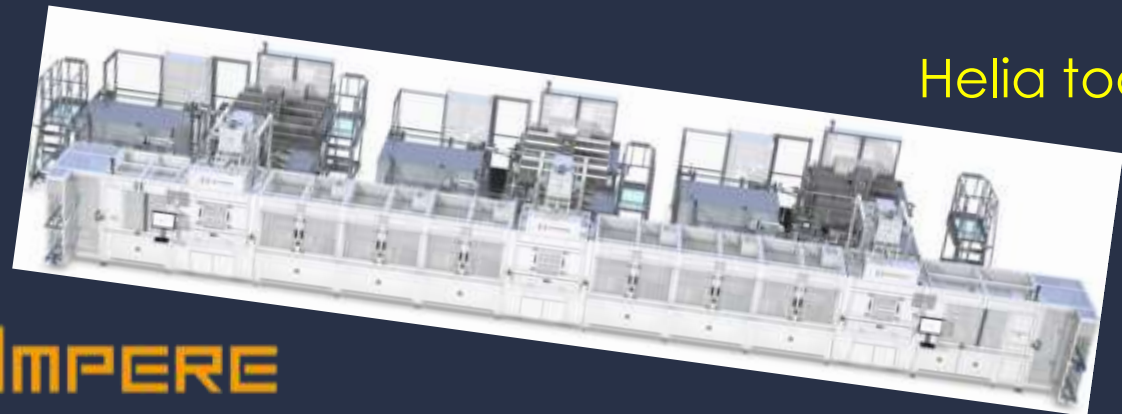
Results achieved with Demo-lines



341W
Module power
(mono *facial*)
M2 cells



- Over 1 GW production lines in constructions
- Up to 92.6% bifaciality



Helia tool

Leading module manuf. REC solar leapfrogging into Heterojunction



Meyer Burger gets 600MW heterojunction and SmartWire tool order

By John Parnell | Dec 14, 2018 11:48 AM GMT

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Sneak peek: REC Group's new solar panel to change the game

- US\$ 150 million investment to create the world's highest power density panel
- Leading technology from Norway, Singapore and Switzerland, pioneered in Germany
- New flagship product to be released at Intersolar Europe 2019



Solar cell and module technologies ready for mass-manufacturing 2019+ | PV CELLTECH 2019

The world's first installation of REC Group's Alpha solar panels

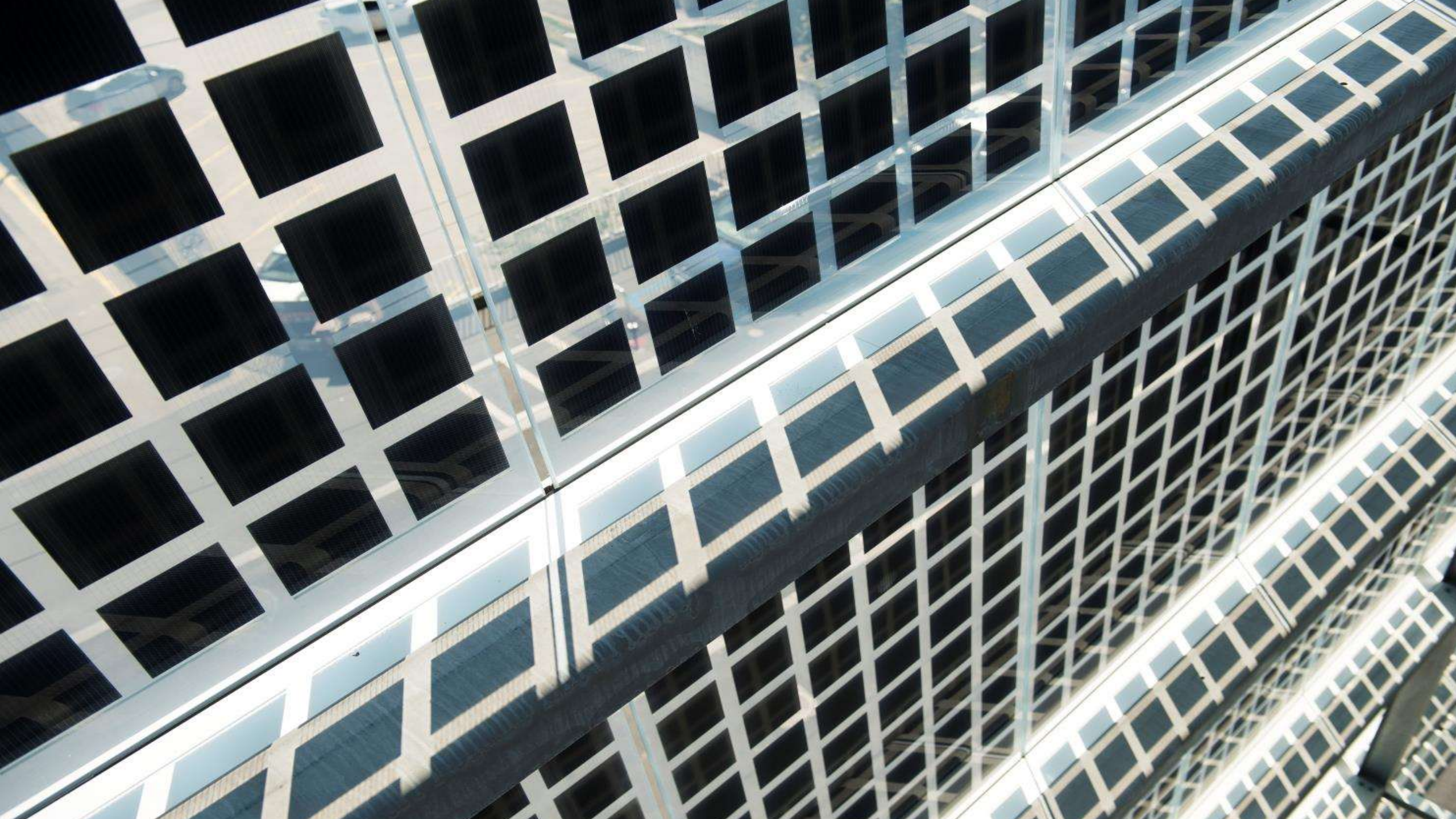
Munich, Germany, October 8, 2019 – [REC Group](#), an international pioneering solar energy company with a Scandinavian Heritage, is proud to announce the world's first installation of its [innovative Alpha solar panels](#) on a home near Venice, Italy. Harnessing power from the sun enables home owners to reduce carbon emissions while saving on their electricity bills – with REC Alpha's industry-leading power output even small roofs can make a difference. This helps the environment and thus preserves places like Venice and many other UN heritage cites whose very existences are threatened by climate change.



- Raised in July 165 millions CHF to pursue their strategy, with first 400 MW production, then targeting 5000 MW, keep R&D, metrology in CH (Neuchâtel and Thun)





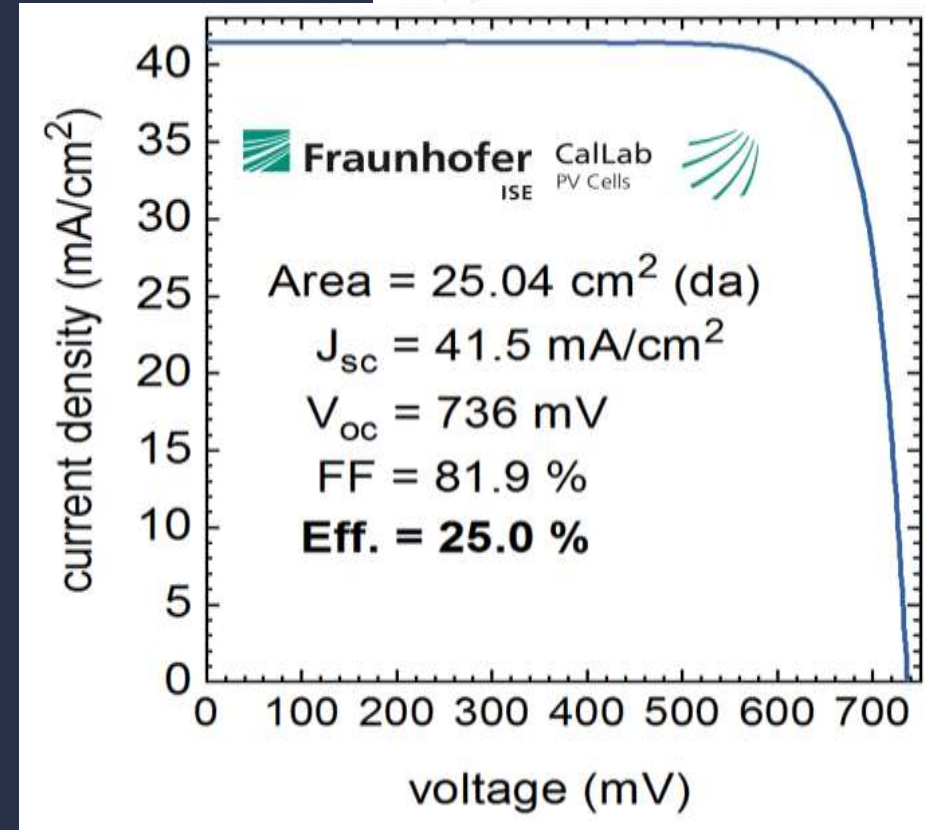
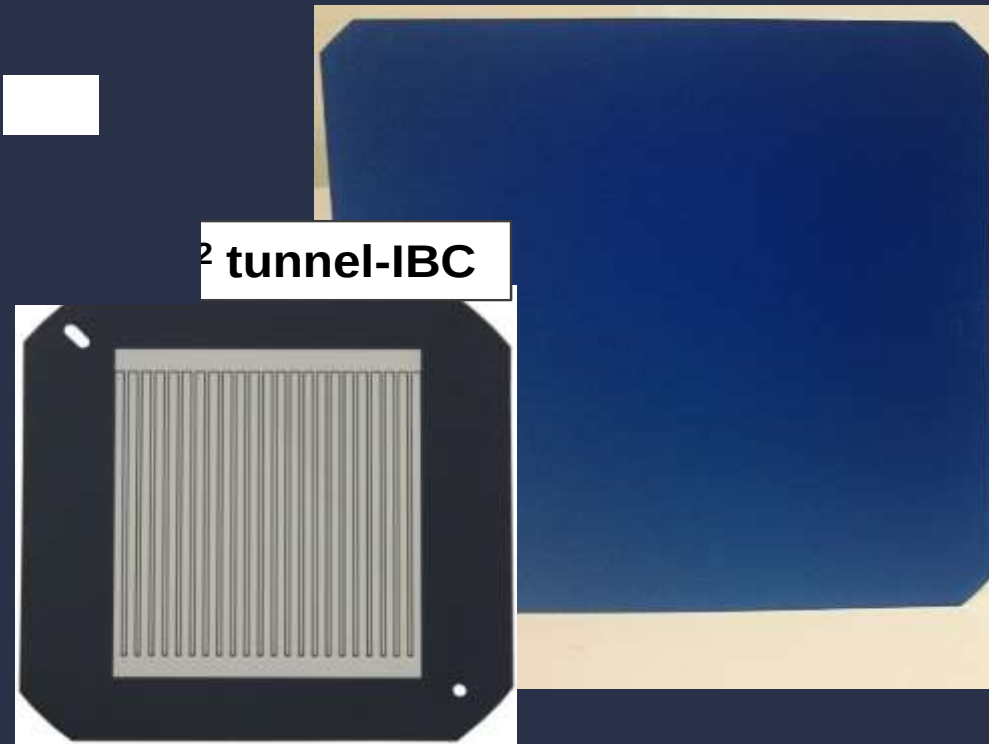


HETEROJUNCTION: UPGRADE SCENARIO to IBC-HJT

- TUNNEL IBC-HJT process of EPFL/CSEM

In 9 process steps

- Selective local epitaxial growth:
- SIMPLE PROCESS FLOW, MINIMIZE MATERIALS (Indium-free)



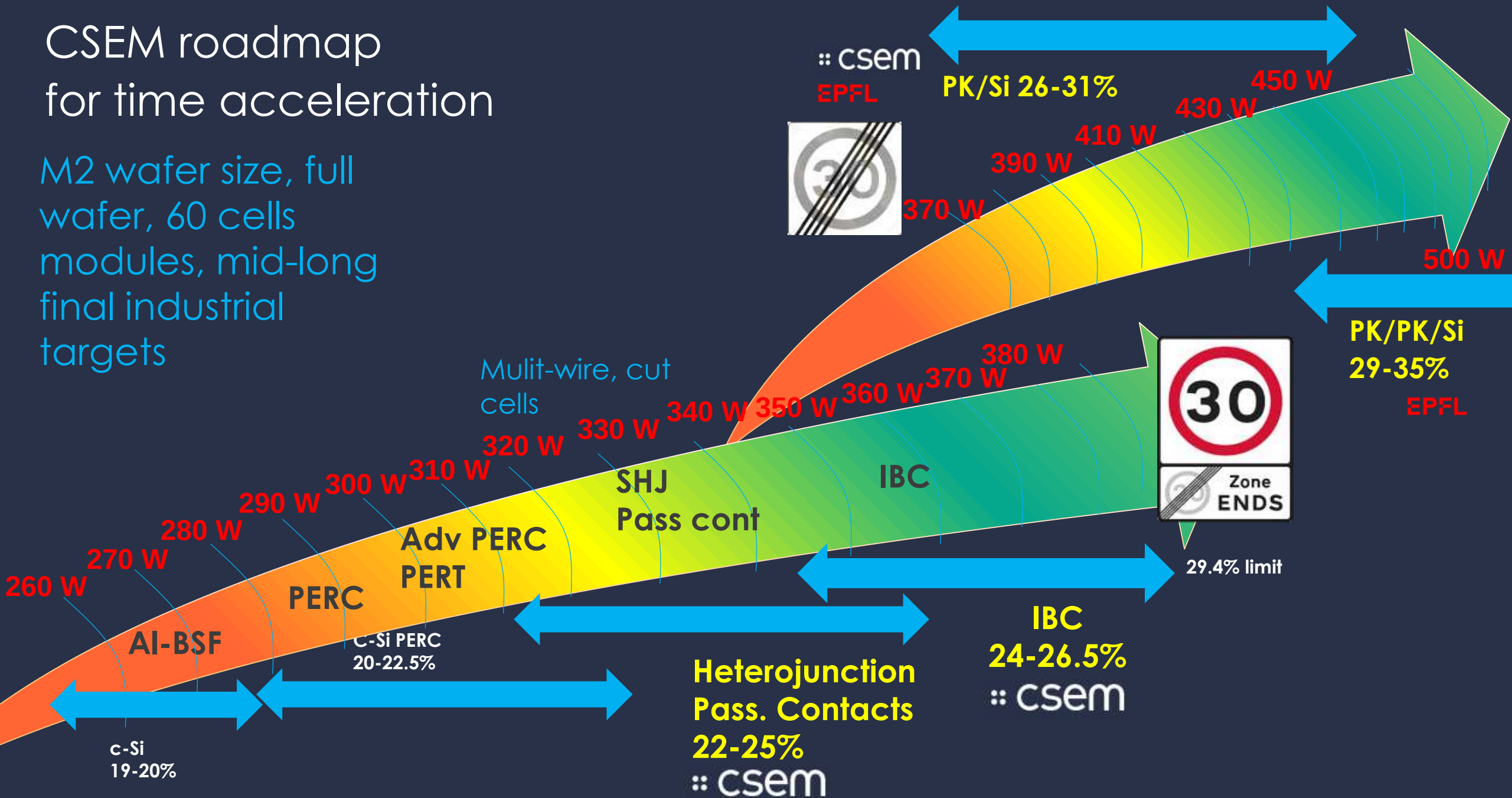
**Certified 25%,
Now at 25.4%**

Goal 26-27%

Tomasi et al. Nature
energy 2017

CSEM roadmap for time acceleration

M2 wafer size, full
wafer, 60 cells
modules, mid-long
final industrial
targets



The current only potential «cost affordable» tandem

Recent examples market application

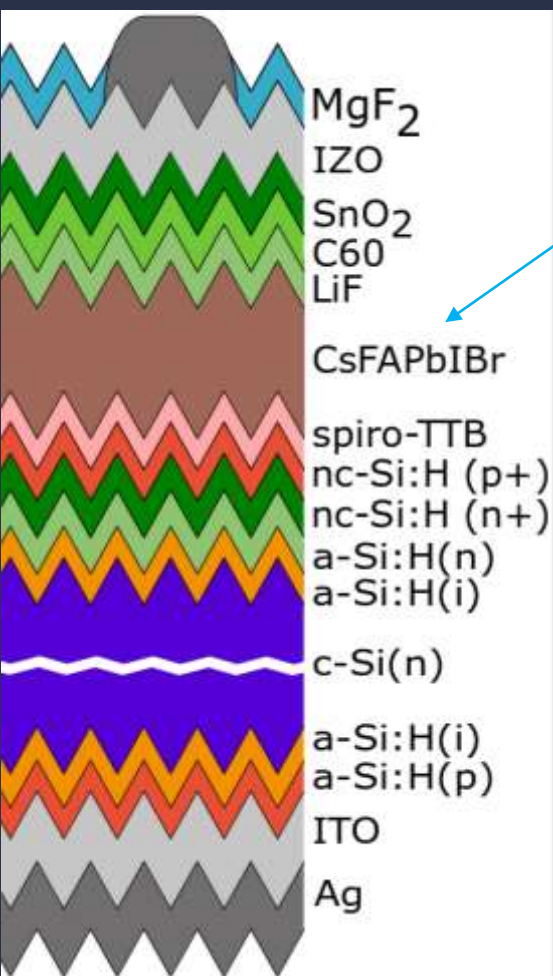


- **Perovskites based solar cells**
- **PK / PK or PK on Si**

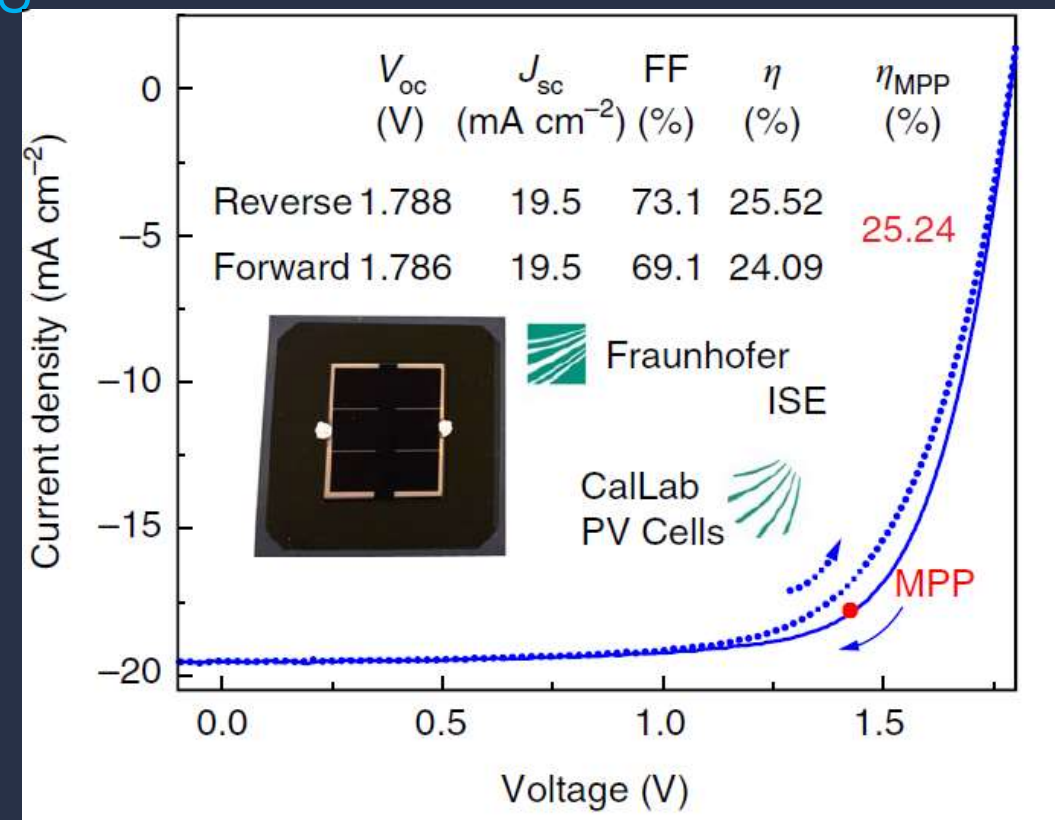
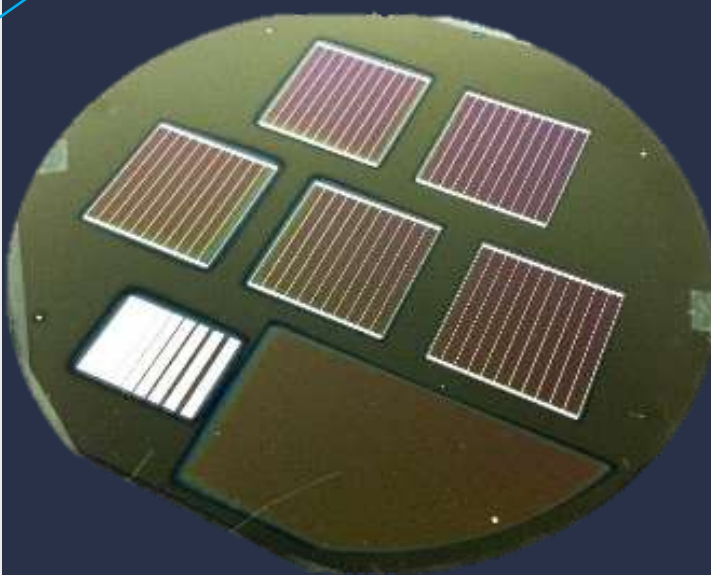
Collaborations EPFL/EMPA/CSEM

First good device on textured wafers: Perovskite cell on Silicon

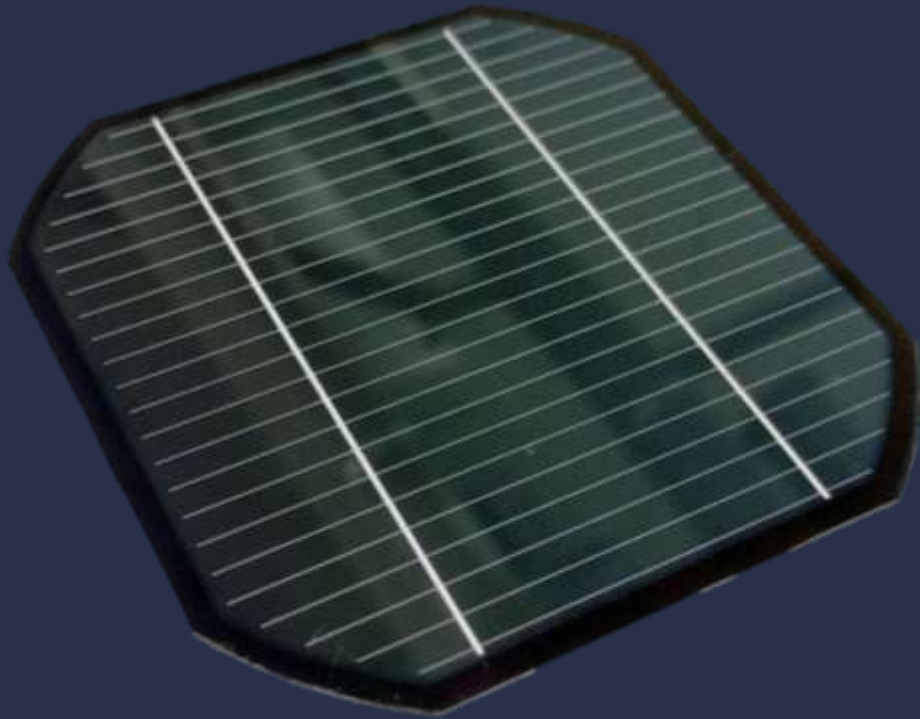
F. Sahli. J. Werner, Nature Materials 2018



Perovskite cell



In June 2018: new world record at 25.3%, potential for 30% at low cost Hzb at 29% in 2020



Tandem solar cells:

First 4 inches Perovskite on silicon

> 24.5 %



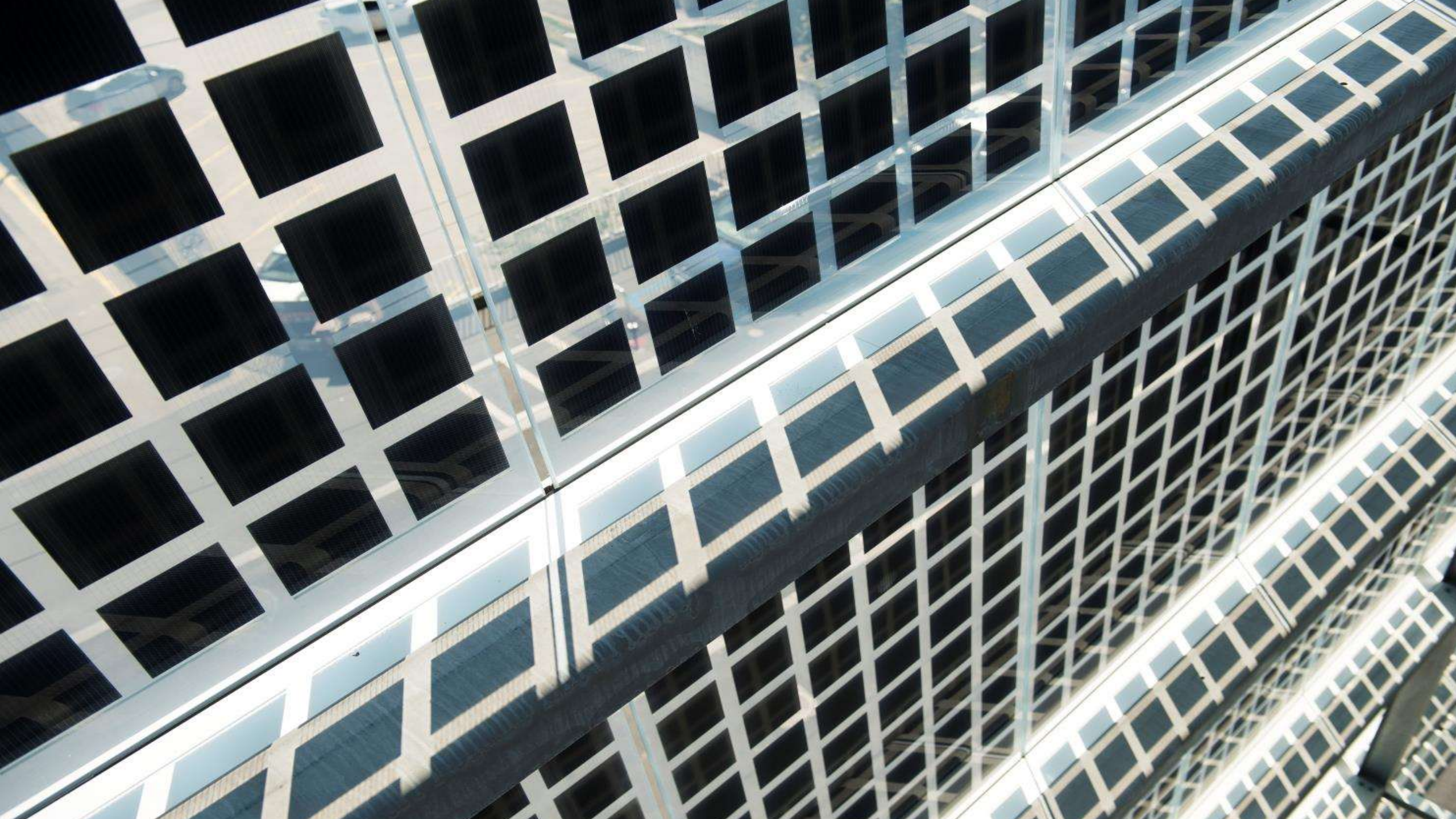
Static concentration, based on space solar cells
but captures diffused light

→ **29% efficiency**

- EPFL start-up



Hyperion: large EU project around Insolight just started !
CSEM manages project and to hosts pilot line.



On peut faire tellement
plus avec le solaire....



Polymers and specialty films for PV: towards ultra-reliable PV



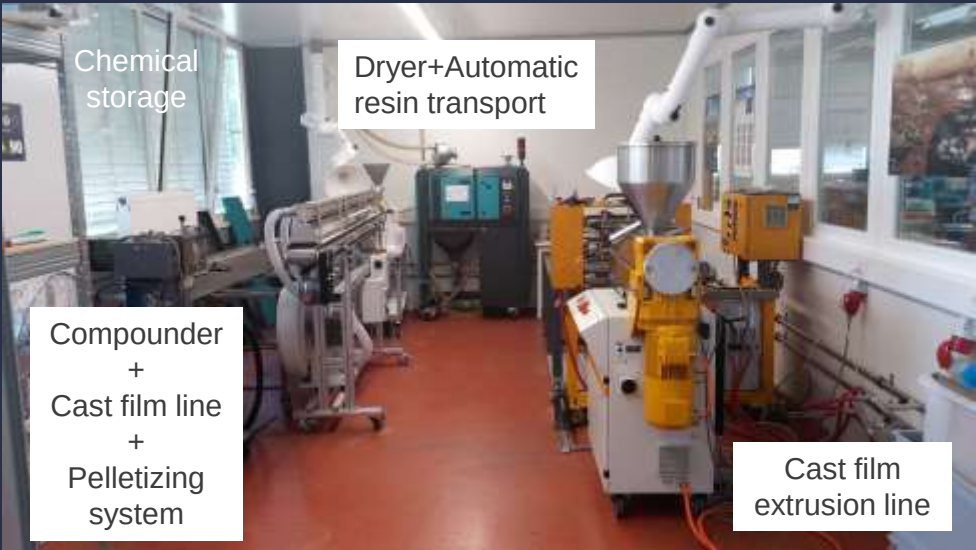
Airplane
and drones



Light weight aerospace



Nautical



Chemical
storage

Dryer+Automatic
resin transport

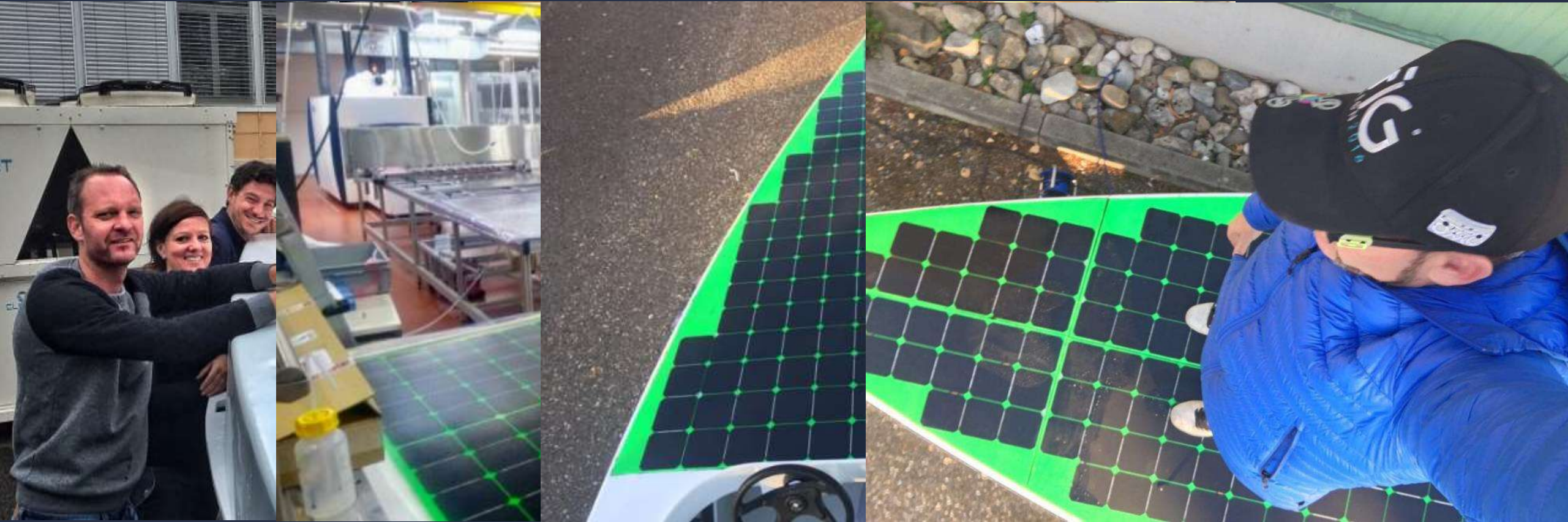
Compounder
+
Cast film line
+
Pelletizing
system

Cast film
extrusion line

Explore

Customized PV products from the water to the air

- High-couture modules for competition boats



Artic solar with Anne Qéméré



Antatartic
2019





Explore

Customized PV products from the water to the air

- Light weight specialty modules for terrestrial and space



Solarstratos first flight

Lightest weight



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DHP (CH)

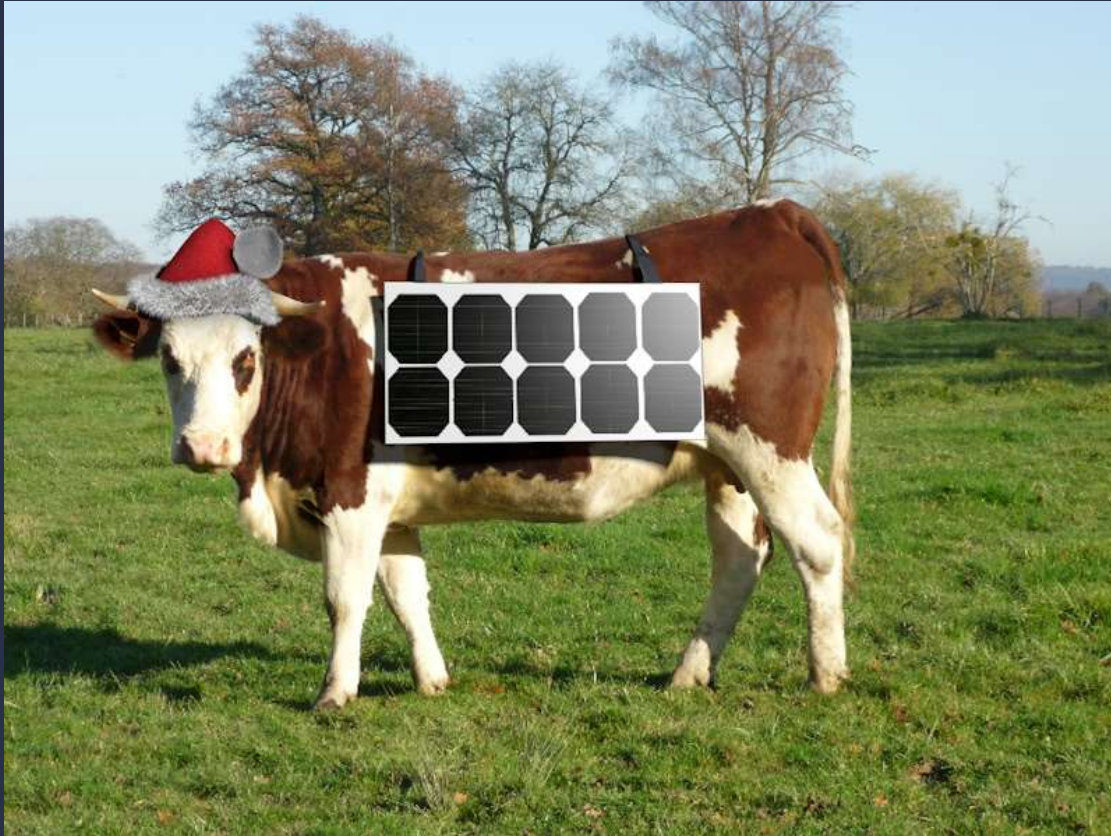
Horizon

- Deployable PV systems
- Over streets, parking, water,....



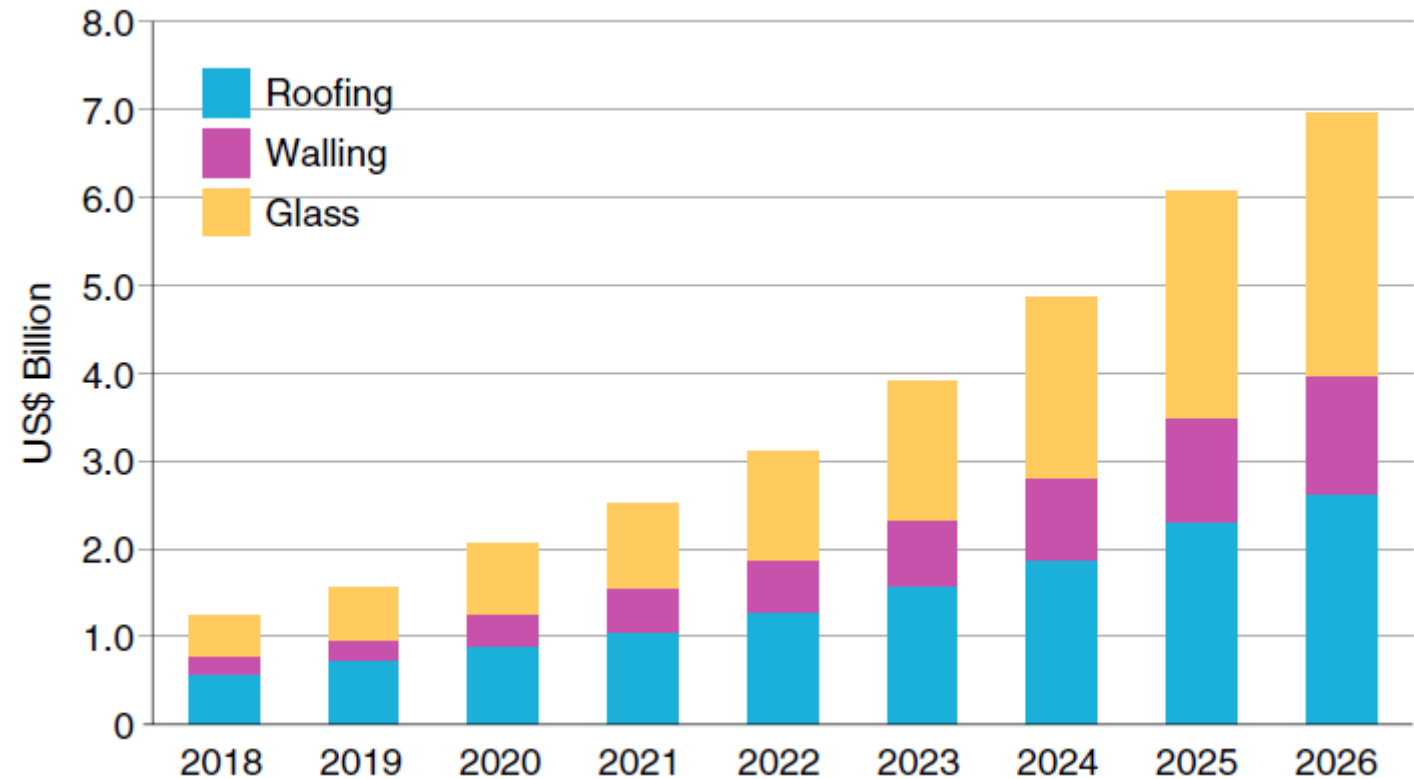
Switzerland, sensitive to acceptance in Rural and Urban Environment

Sensitive to aesthetics



Growth market

- BIPV: a (in principle) 40% growth market



BIPV Technologies and Markets: 2017-2026 (n-tech Research, 2017);

Elegance and architecture

Transforming building and cities, renovating houses



3S solar plus, Swiss Inso,
Solaxess, Freesuns, Megasol,
Schweizer, Sunstyle, Eternit,
Glass Troesch, Panotron, ...



Managed by EPFL

Dr. Laure-Emmanuelle Perret-Aebi, PV-lab



Freesuns solar tiles / Colombier sur morges



- Neuchâtel, maison des associations, Swiss Solar Award 2015 «renovation category»
- Over 10'000 “megaslates” systems installed

Prix solaire

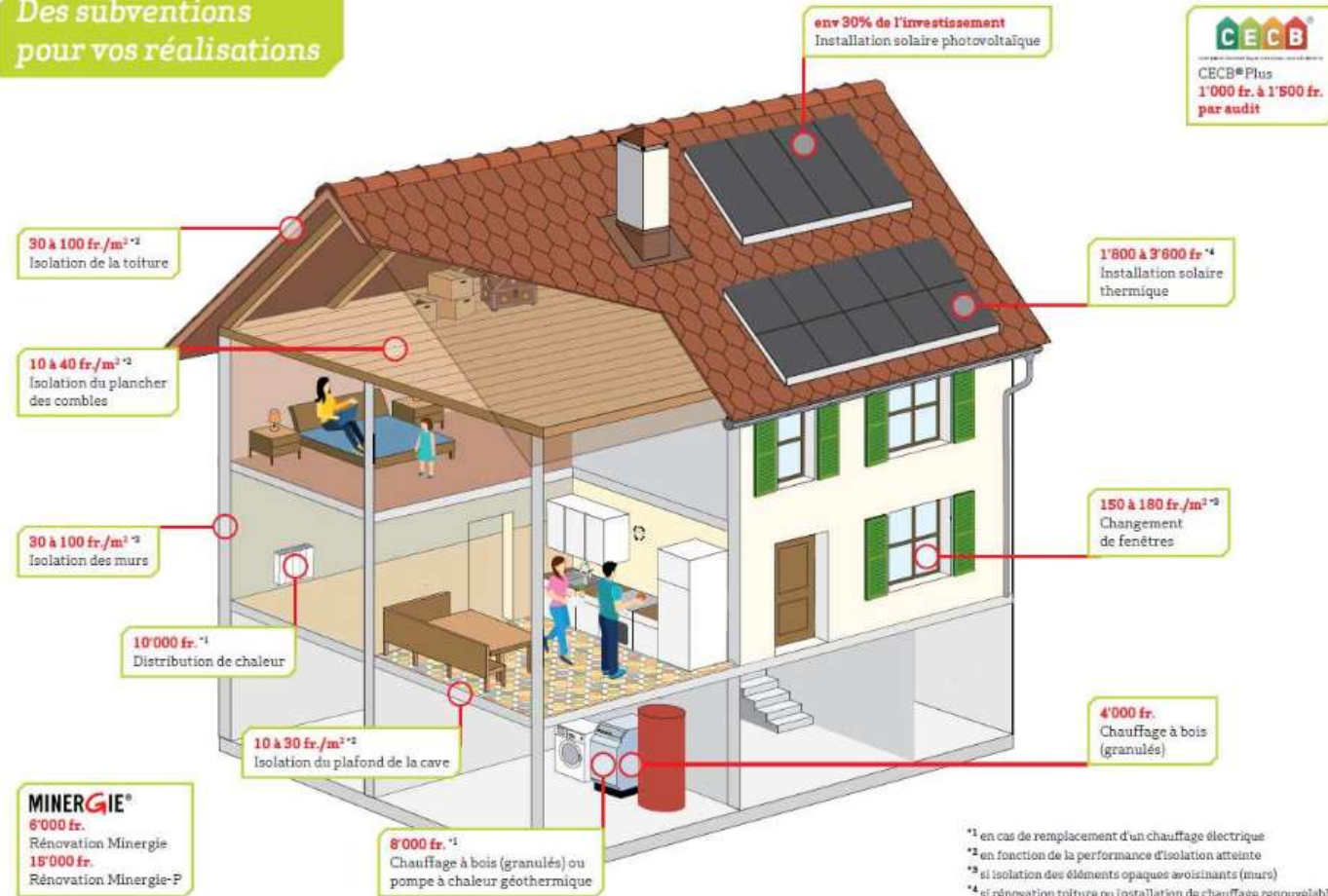
Suisse 2015



PV onto buildings: what we should **not do** in Switzerland !

Aides financières pour le bâtiment

Des subventions
pour vos réalisations



Small PV systems
on a large roof
Should be
discouraged

All good roof
surfaces should be
covered with PV

70

Le photovoltaïque en Suisse et dans le canton de Vaud, Renens, 2 juin 2016

15

When required: make PV integrated and better looking system



One of my Neighbourg:

Full roof renewal

More expensive to integrate
PV than to add PV

how to solve that ?

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Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Elegance and architecture

Prix solaire

Suisse 2018

Transforming building and cities, renovating houses



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Ecuvillens

- 27 kWp
- 28'000 kWh during 1st year of operation
- One of the Terra-cotta tones
- With ISSOL, Solstis, Userhuus, SFOE
- Soutien des Service de l'énergie et des

nature energy

Photovoltaics
blends in

c. Ballif et al. Nature Energy 2018

75



Prix solaire

Suisse 2019

With support of











Elegance and architecture

Transforming building and cities: New crystalline tiles in protected environment

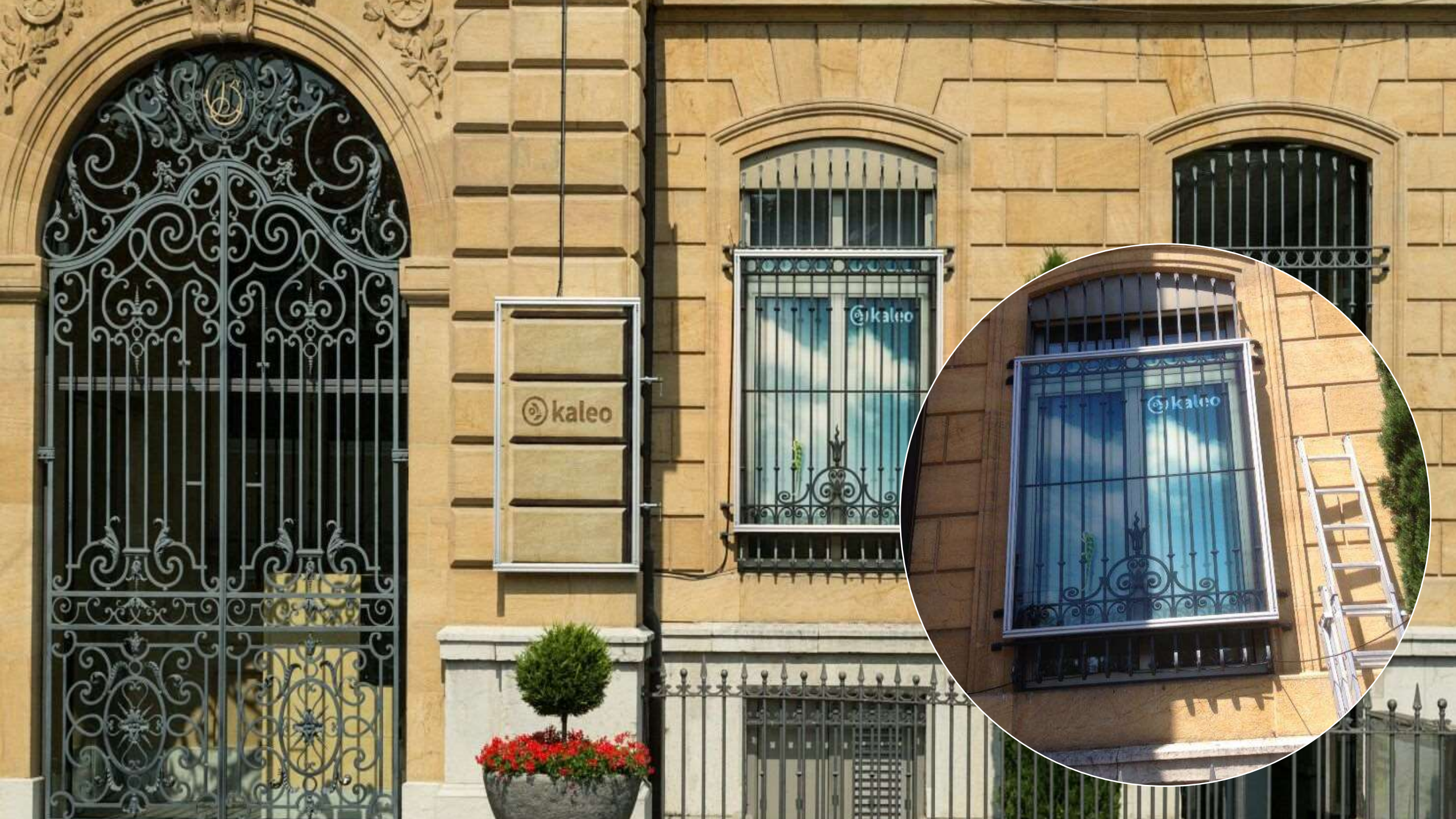
- *Modules with colored meshes of a Swiss Supplier*
- *DSSC module from H-Glass*



The Kaleo project

Up-to where can you modify PV ?







Banque Cantonale Neuchâteloise





Banque Cantonale Neuchâteloise





Nicolas Bideau,
directeur de
Présence Suisse

National
Museum of
China in Beijing
Nov. 2019



Private house
Neuchâtel



Conclusion



- Globalement le PV devient la source d'électricité la moins chère
- Les piliers d'un monde décarboné seront eau-soleil-vent et stockage
- En suisse, solariser toute toiture et en partie des façades devrait devenir la norme, et la responsabilité de tous
- De nombreuses solutions, du low au high end sont disponibles
- Et la Suisse détient de nombreuses technologies clés

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“Jamais le soleil ne voit l'ombre”

Léonard de Vinci

