FROM RESEARCH TO INDUSTRY

OVERVIEW OF PV TECHNOLOGIES

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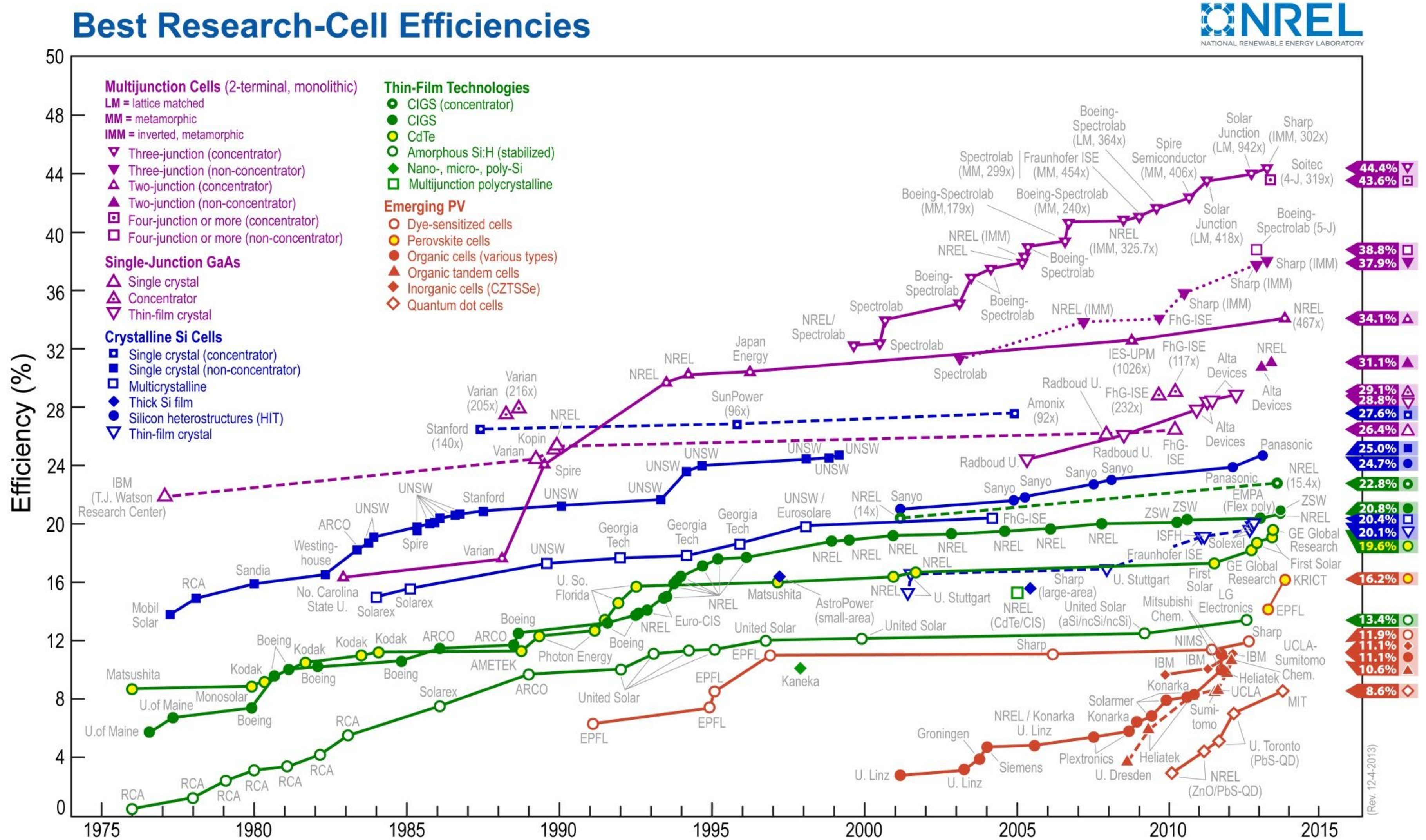
Outline

1. **Past evolution of technologies:**
   - Which technologies
   - Efficiency
   - Market shares

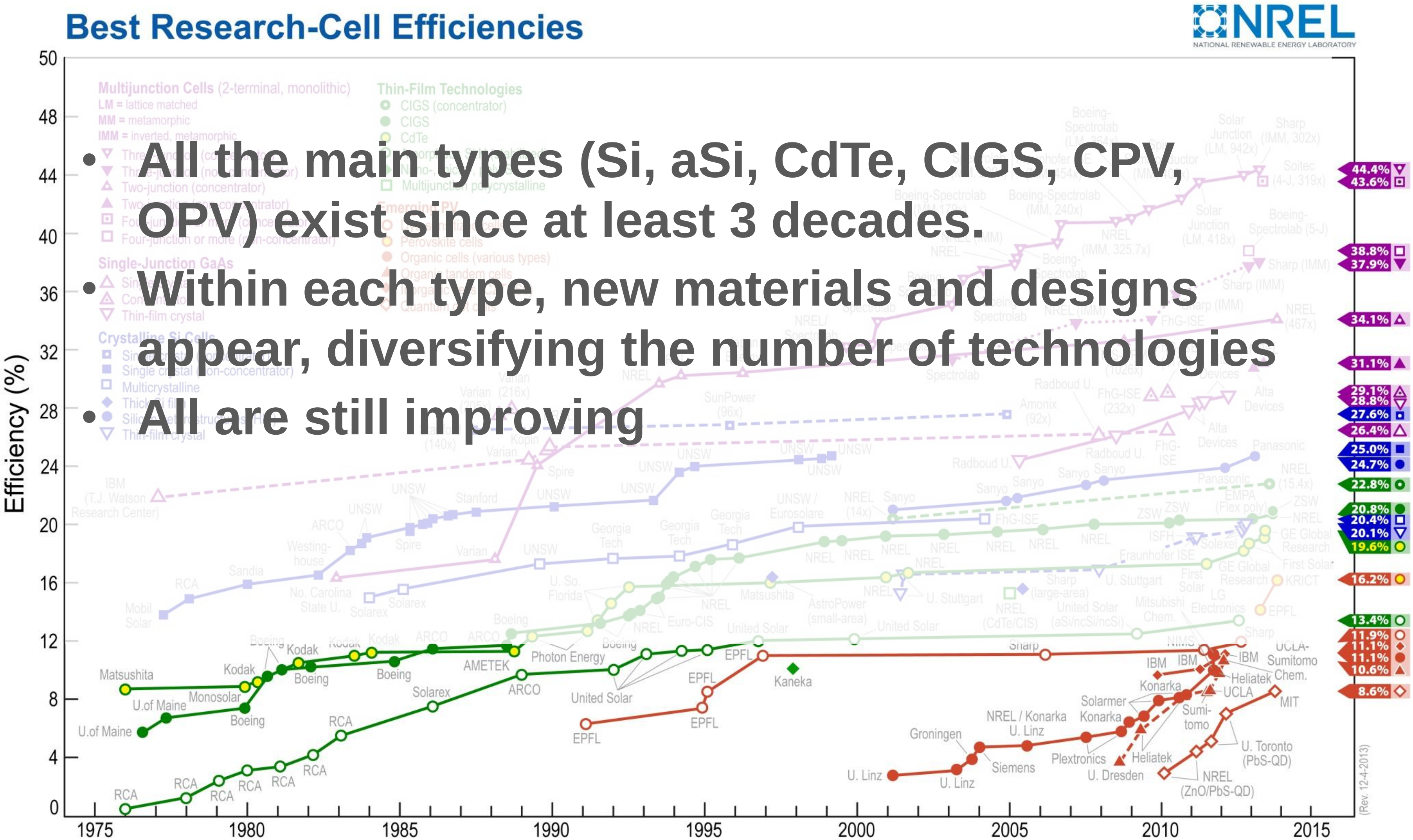
2. **Current research and development**
   - Less material and consumables
   - New materials
   - New cell designs
   - New high throughput processes
   - Optimisation of the supply chain
   - New PV modules and PV-integrated products

Best Cell Efficiencies

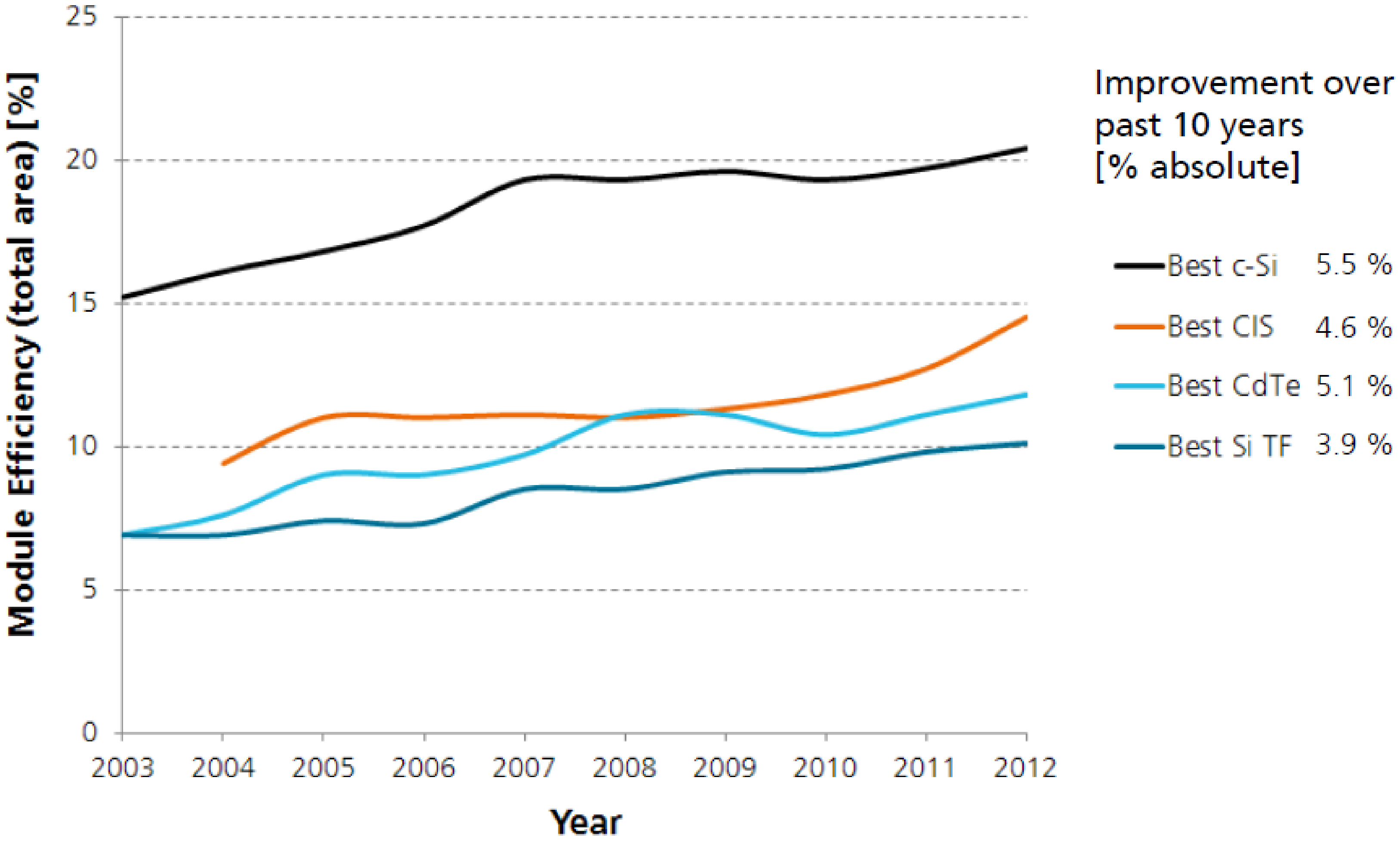


Best Cell Efficiencies

- All the main types (Si, aSi, CdTe, CIGS, CPV, OPV) exist since at least 3 decades.
- Within each type, new materials and designs appear, diversifying the number of technologies
- All are still improving

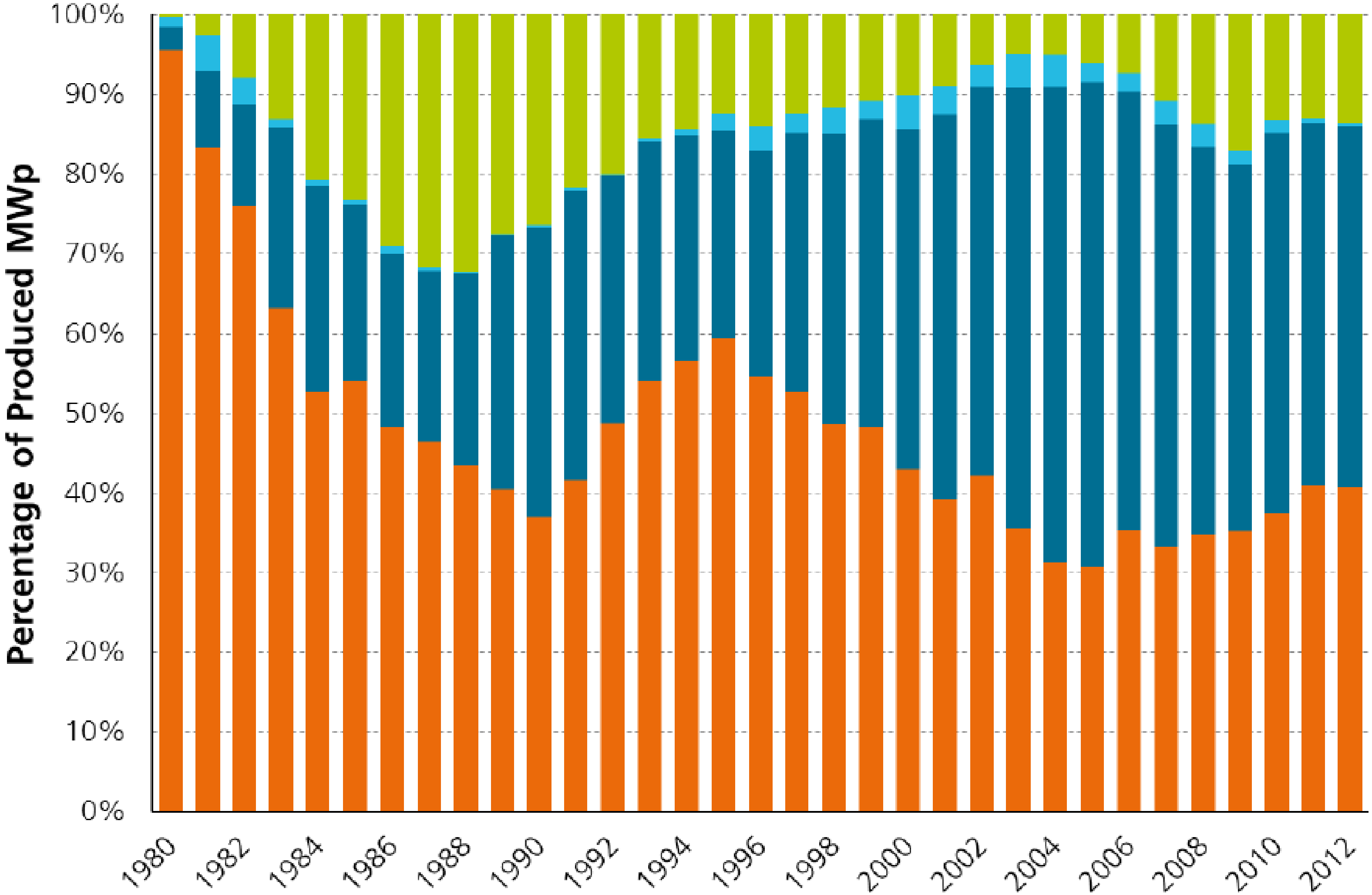


Commercial PV module efficiencies - best figures



Data: Photon 2/2003-2009, Photon Profi 2/2010-2/2012. Graph: Willeke Fraunhofer ISE 2013

TECHNOLOGY SHARE OF SHIPMENTS OVER TIME



Data: Navigant Consulting; for 2012: estimate from different sources (Navigant and IHS).. Graph: PSE AG 2013

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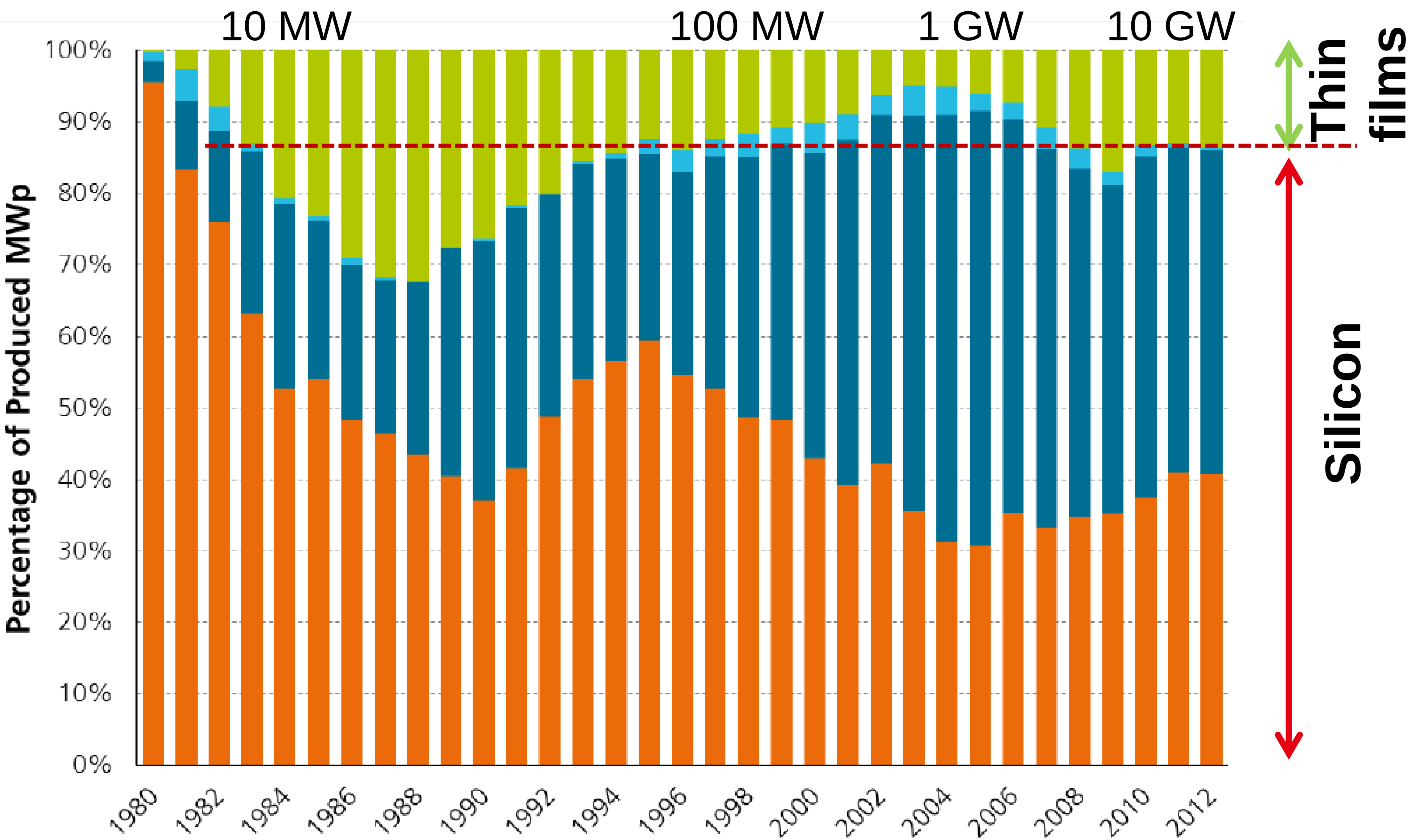

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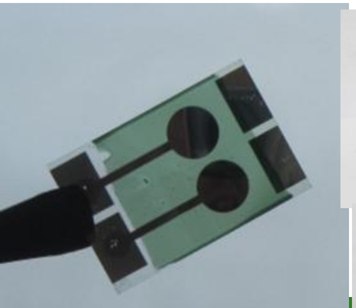
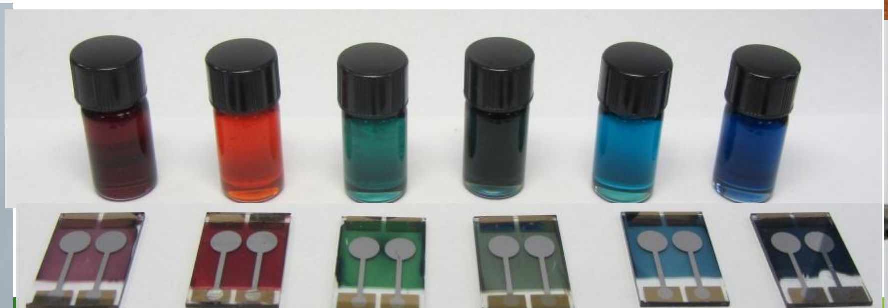
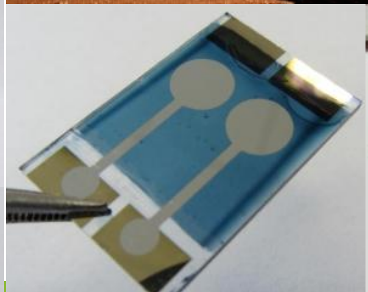
COMMENTS

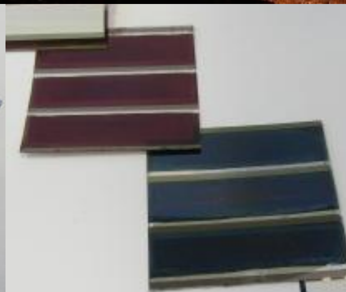
- **All technologies have made impressive improvements to keep up with this x10^3 volume increase**

- **According to IHS, no big change in this distribution is planned until 2020,**
  … which means that most technologies will increase their manufacturing capacities









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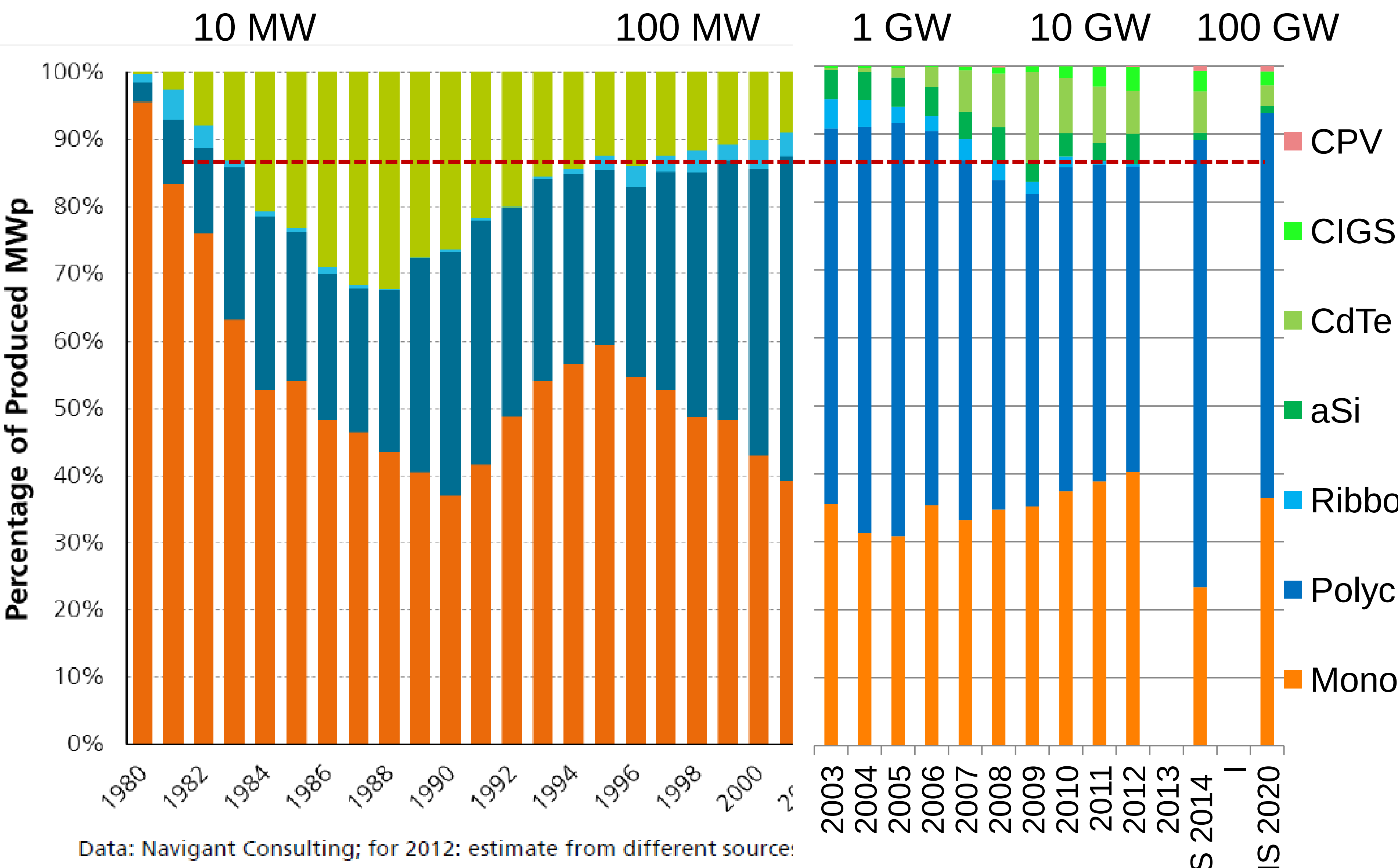

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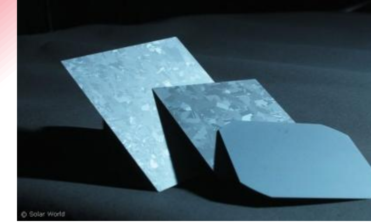
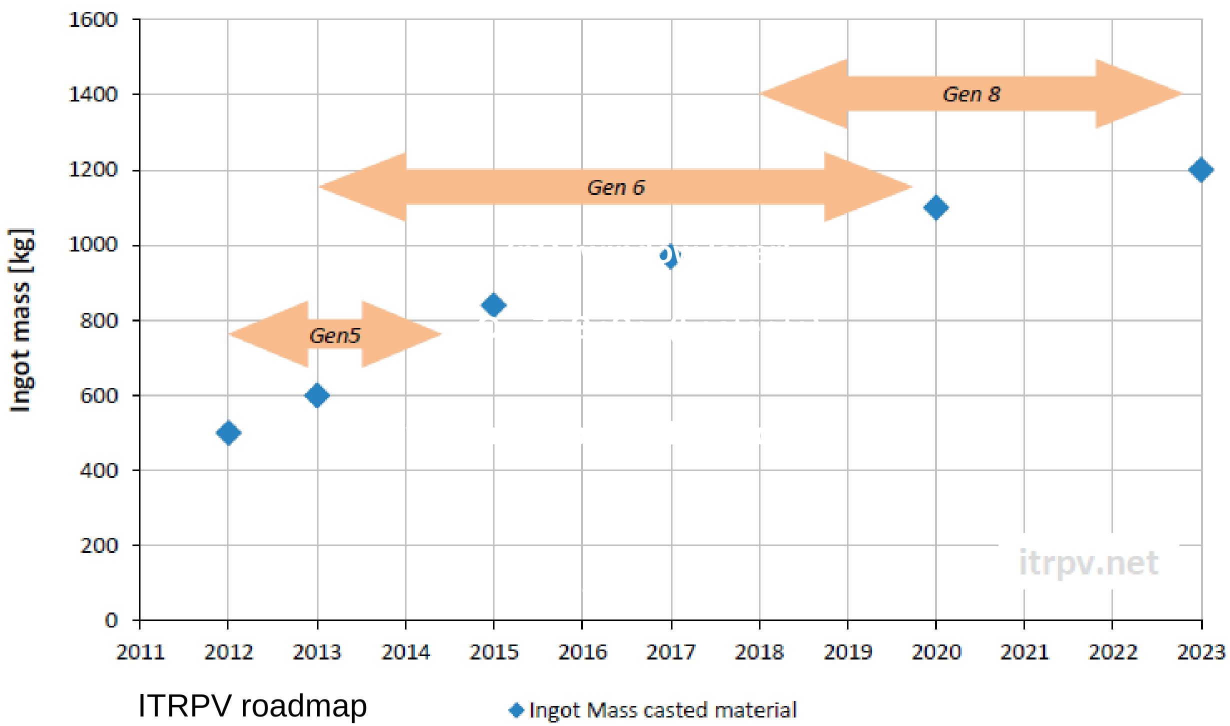
WHAT CAN BE SEEN NEXT ?



At material level

- Poly-Si feedstock production technologies still show improvement potentials (energy efficiency, recycling)
- Increasing the throughput of the crystallization process, while maintaining or improving quality



ITRPV roadmap

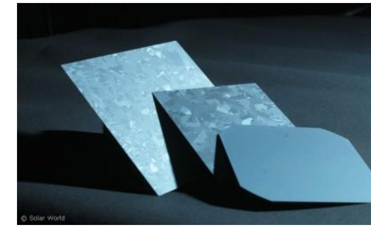
Fig. 13
Predicted trend for mc-Si, mono like and HPmc-Si ingot mass indicating the type of crucible generation in mass production.

Towards cheaper silicon material

WHAT CAN BE SEEN NEXT ?

At material level

- Consumables such as gases, graphite parts, and crucibles bring cost reduction potential
- Thinner wafers, on the way to 3g/W
- Introduction of diamond wire sawing



Mid & long term:

- reusable crucibles
- direct wafering (2g/W)

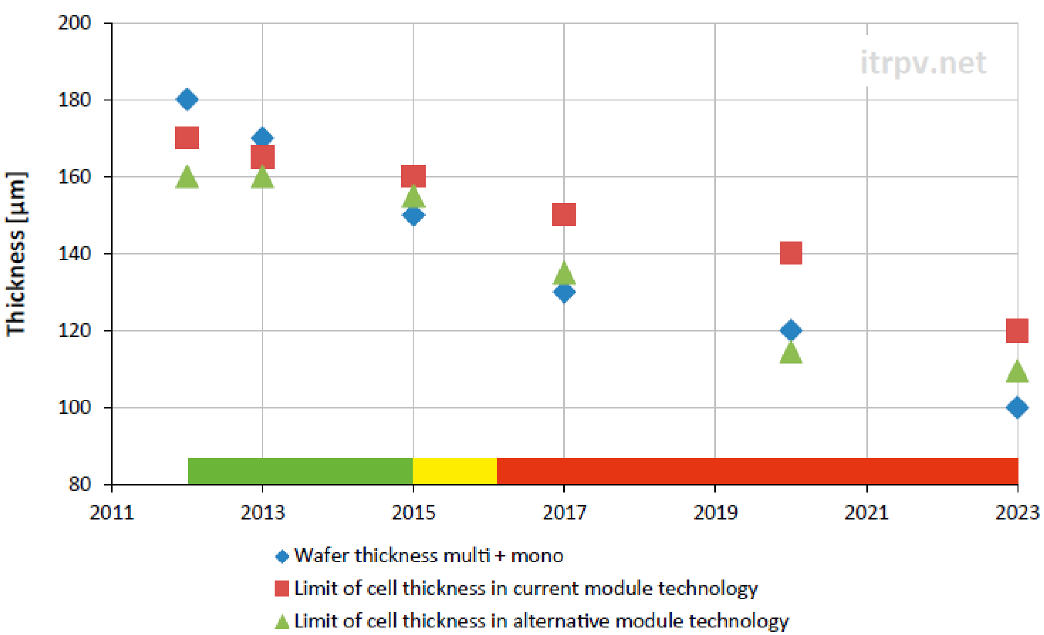
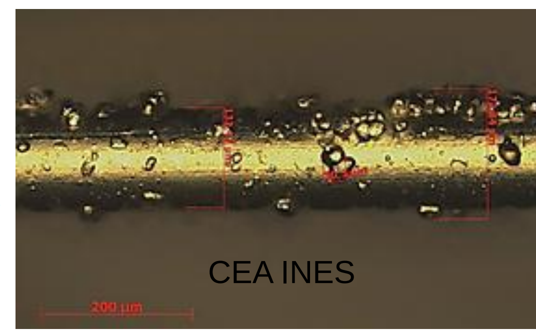


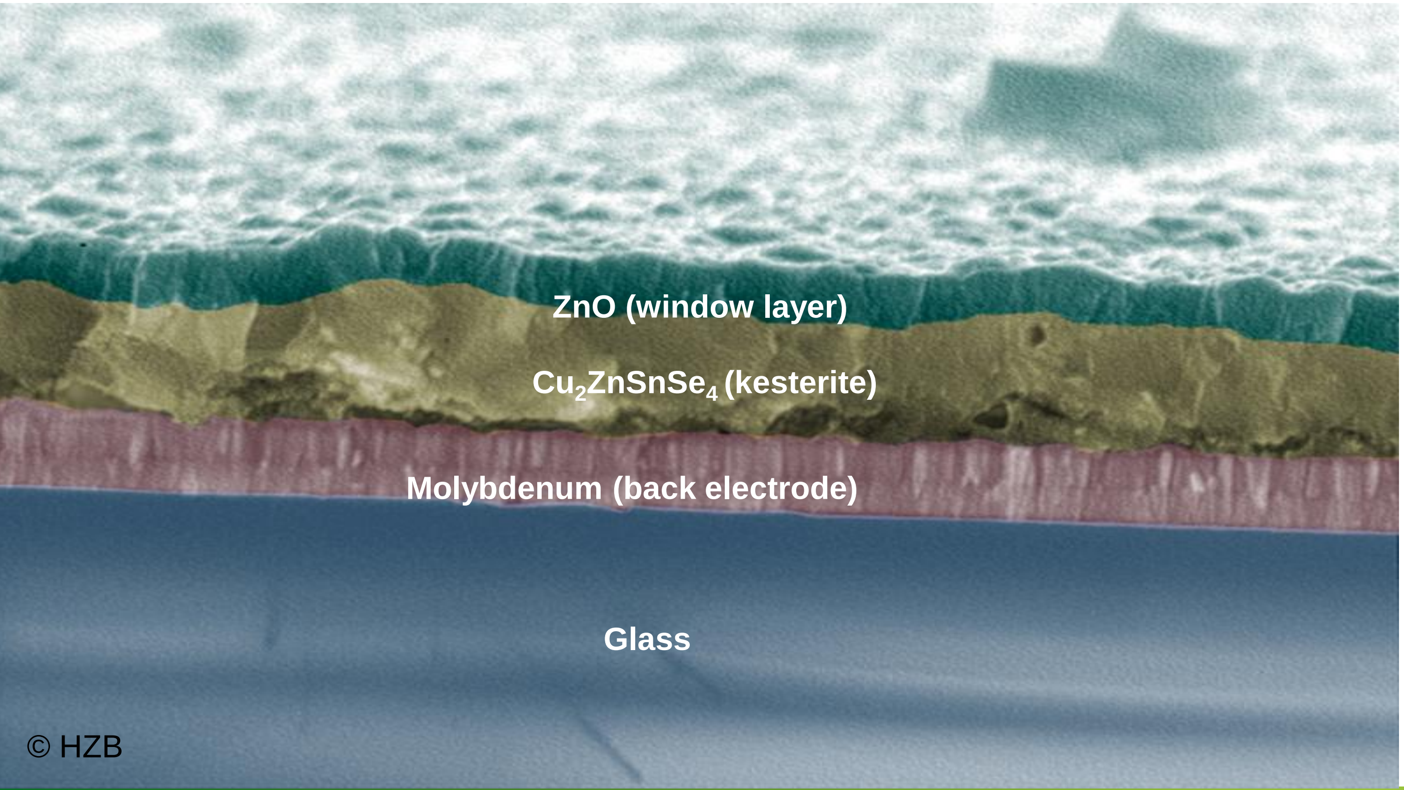
Fig. 7
Predicted trend for minimum as-cut wafer thickness in mass production of solar cells and minimum cell thickness in module manufacturing.



Cost reduction through less consumables and material

At material level

- Increasing material quality, the throughput of the crystallization process and designing thinner layers also applies to thin films



WHAT CAN BE SEEN NEXT ?

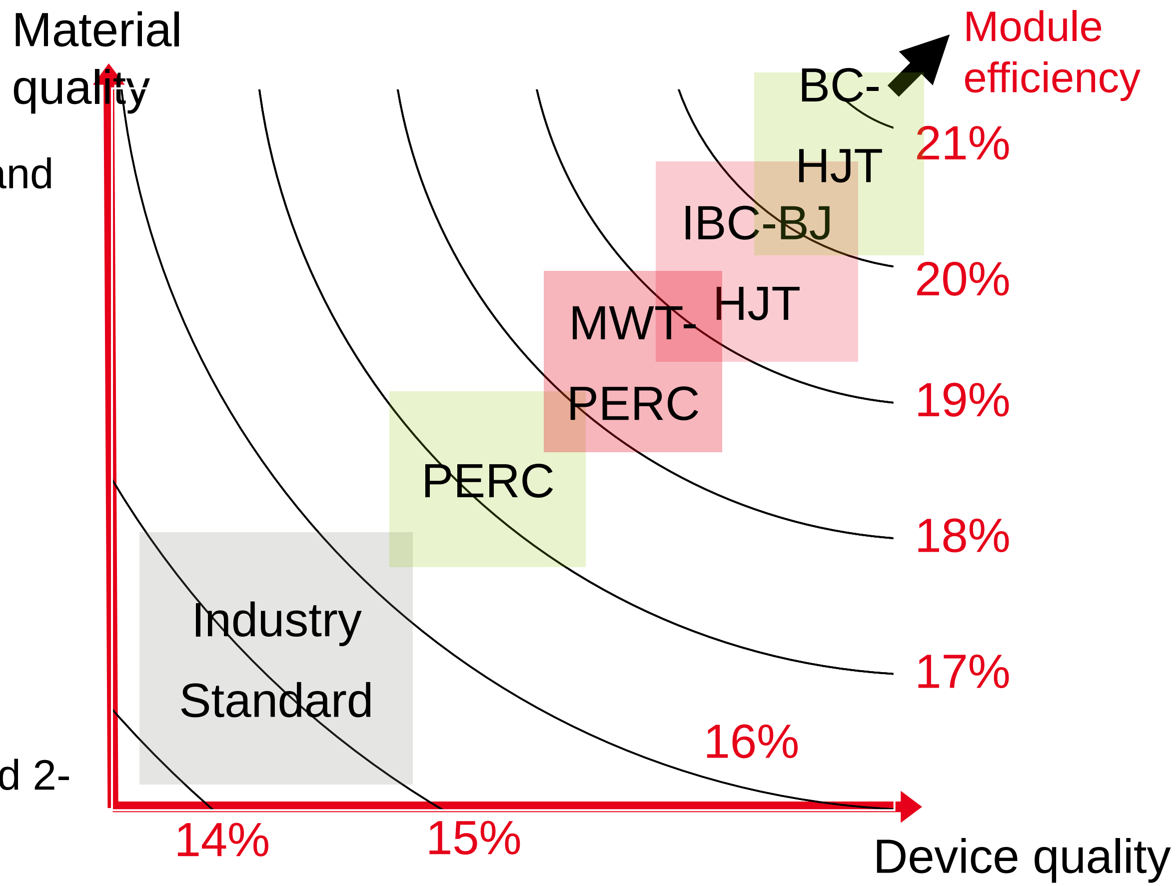
At Si cell level

1. Current cell Structures

- PERC: Passivated Emitter and Rear Cell
- MWT: Metal Wrap Through
- IBC-BJ: Interdigitated Back Contact – Back Junction
- HJT: Hetero Junction Technology

2. New cell designs

- Thinner
- Heterojunction with 3-5 and 2-6 semiconductors



Adapted from Preu et al., EU-PVSEC 2009

Many improvements to come : efficiency & costs

WHAT CAN BE SEEN NEXT ?

At cell level

- Metallisation :
  - Reducing Ag consumption,
  - Introducing new technologies : electroplating, light induced plating
- Increasing efficiencies decrease module and system cost

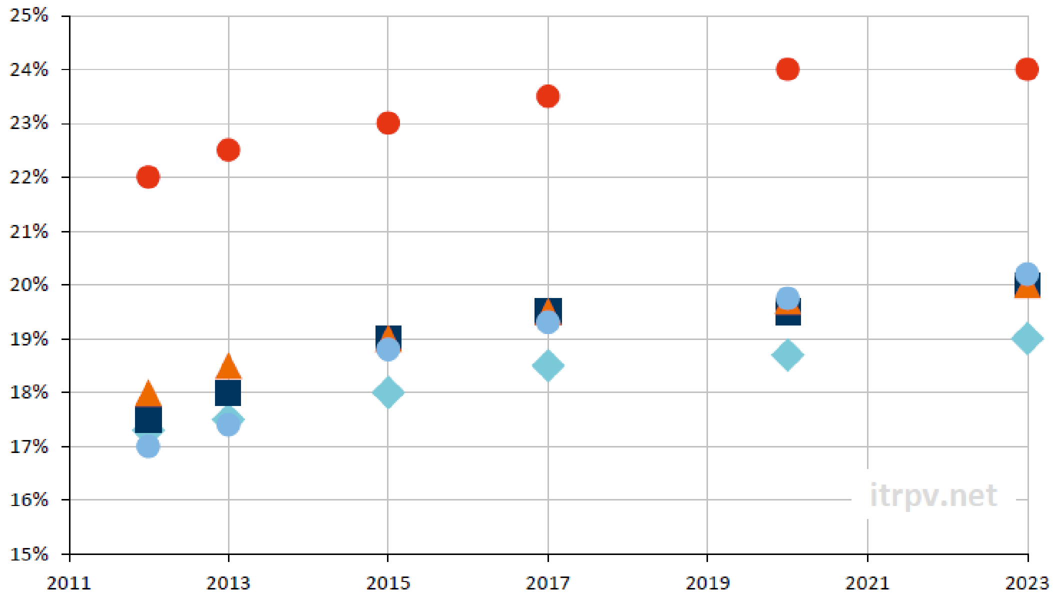
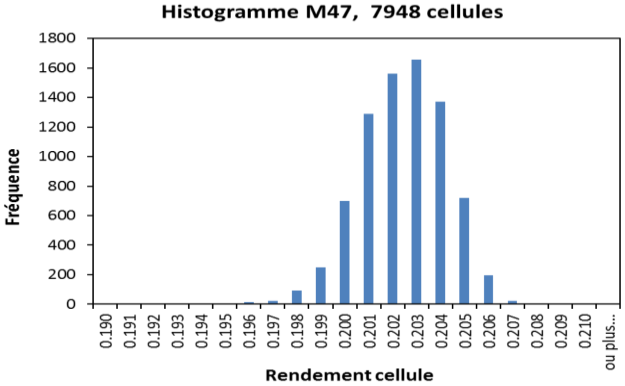


Fig. 31
Cell efficiency trend for different single-sided contact c-Si cell concepts.

WHAT CAN BE SEEN NEXT ?

New high-throughput processes : i.e. HET, with in line TCO and a-SiH deposition

INES CEA record HET cell 22,2%



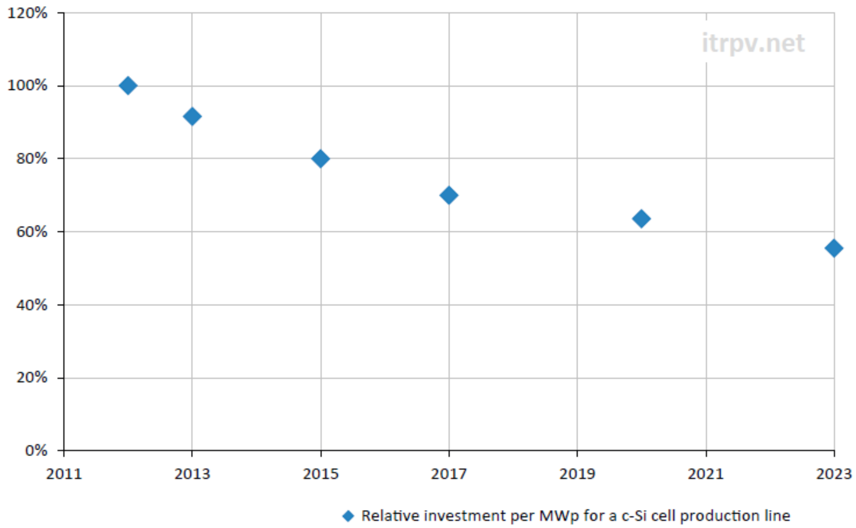


Fig. 19
Chart showing the relative investment per MWp for a c-Si cell production line.

Pilote lines are key to check and guarantee performance and costs, before large-scale investments

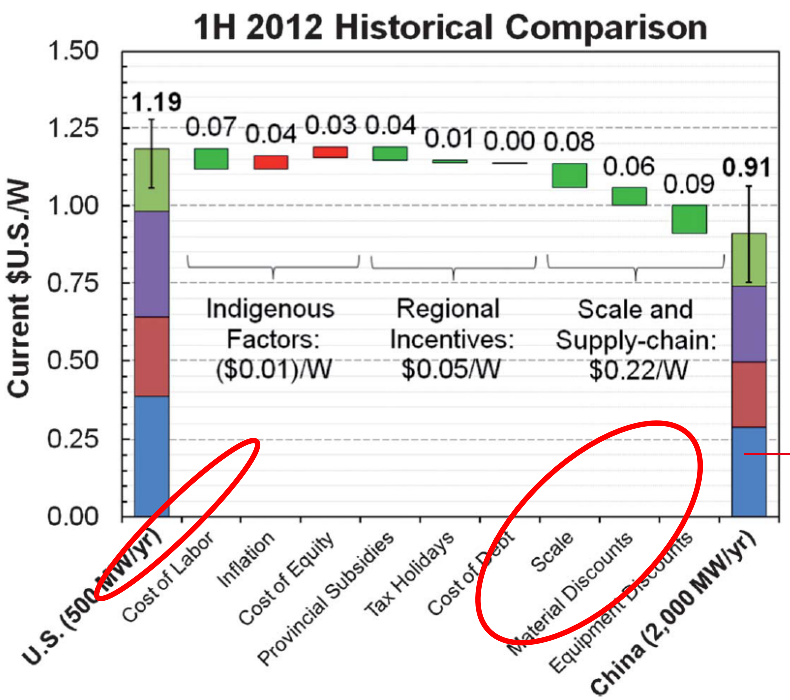
LOCAL CONTENT ?

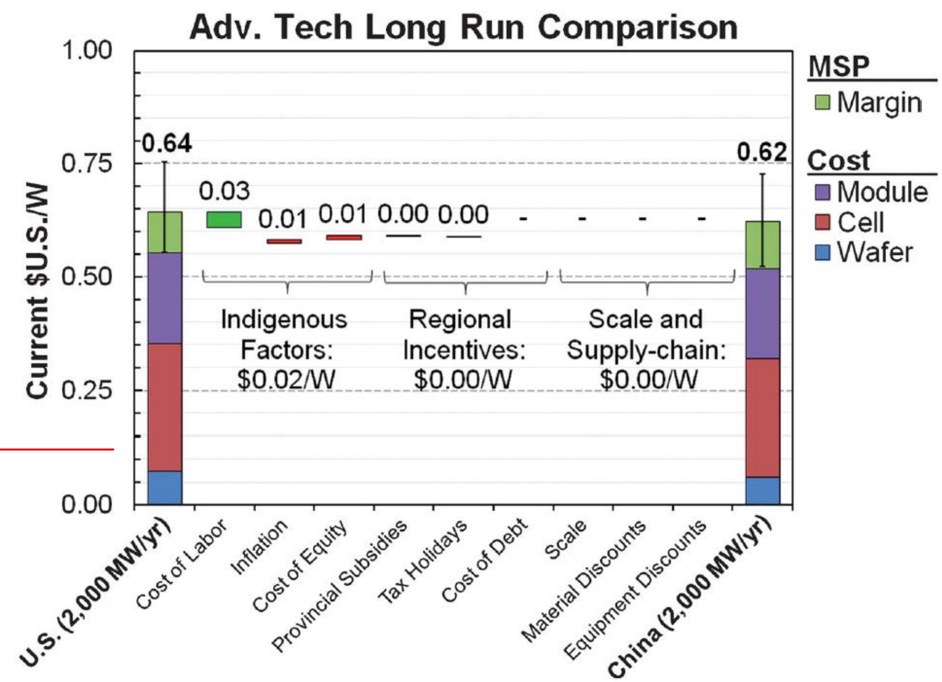
Local production remains possible with optimal supply chain and advanced and highly automatized manufacturing

Alan C. Goodrich,*[a] Douglas M. Powell,*[b] Ted L. James,[a] Michael Woodhouse[a] and Tonio Buonassisi*[b]

Energy & Environmental Science

NREL + MIT





Assumptions:

- *22,4% n-type advanced cells*
- *Automatized and large size manufacturing (reduced material and installation costs)*

WHAT CAN BE SEEN NEXT ?

At module level

Short-term

- Efficiency increase
- Size and power increase
- Thinner glass
- Mass reduction of module frames

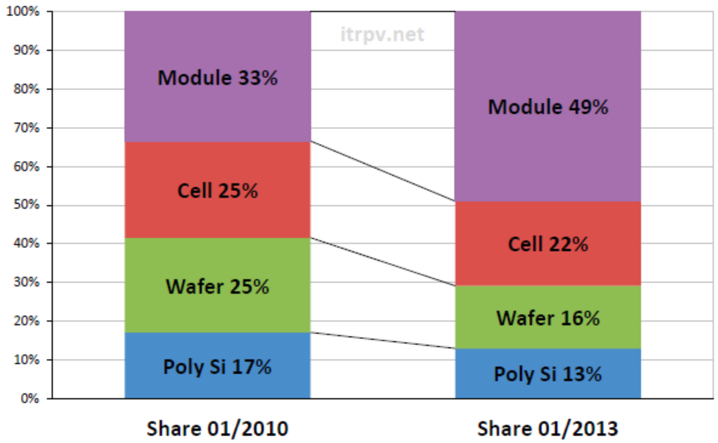


Fig. 3 *Comparison of the proportion if cost attributable to different module elements between 01/2010 and 01/2013 (1.87$ and 0.69$/W).*

Mid and long-term

- Diversification of materials
  - Glass/glass and glass/backsheet
  - Acrylic, polymers, etc.

- Diversification of shapes for:
  - Better integration to specific requirements and applications
  - Additional functionalities
  - Cheaper installation

Examples in new buildings : Façades


solarte@free.fr


solarte@free.fr


solarte@free.fr

solarte@free.fr

www.2es.fr

Examples of specifically designed BIPV products:
See-through modules

- With cSi cells

Tsukuba building, view from inside

From outside

Examples of specifically designed BIPV products:
See-through modules

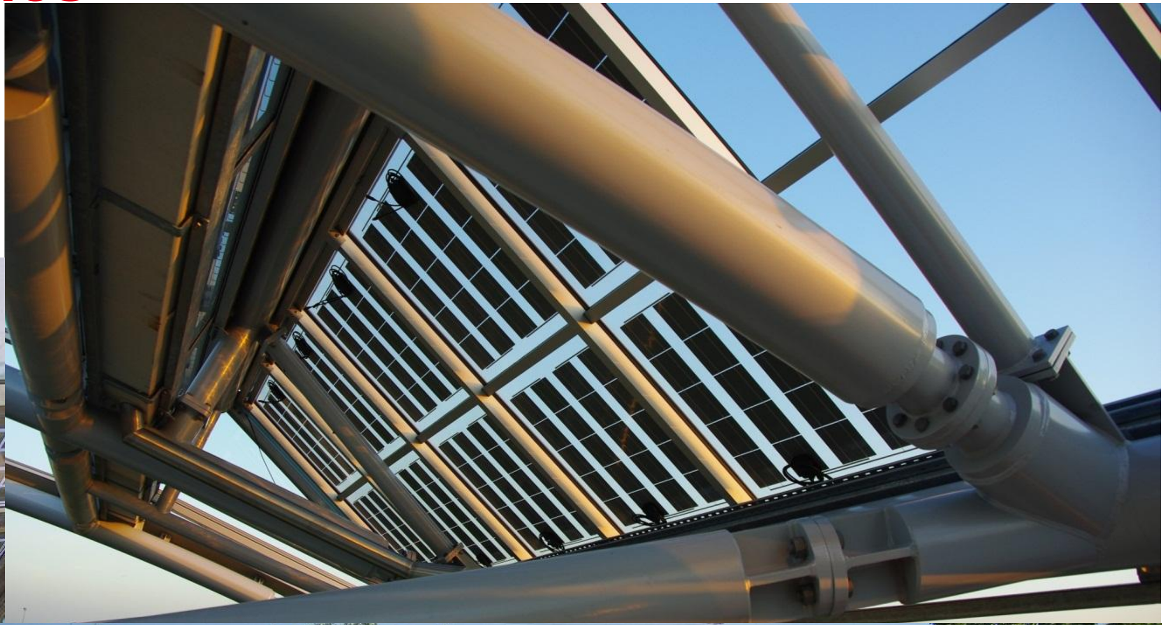
- **With cSi cells**

www.batisolar.fr

Examples of specifically designed BIPV products: See-through modules

- **Cell spacing adapted to lighting, heating and cooling requirements**

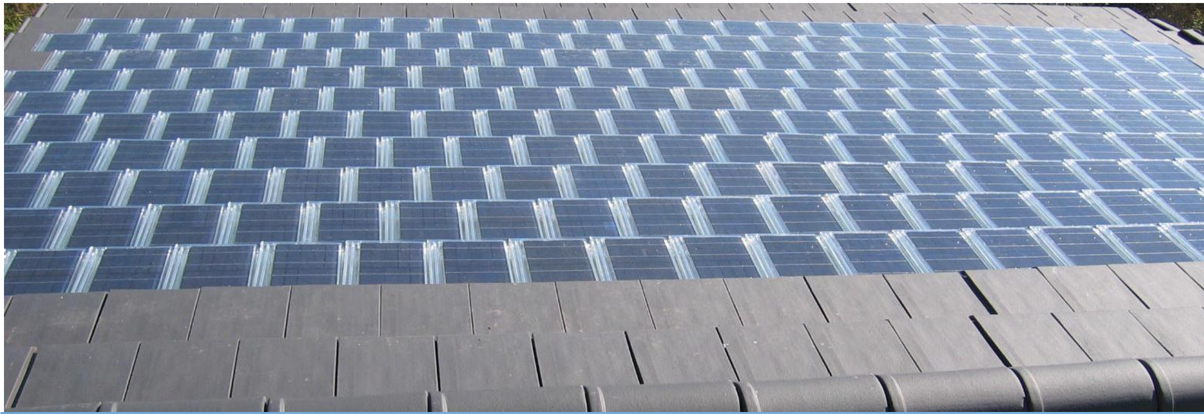
www.terrecielenergies.com



- **With thin film technologies**

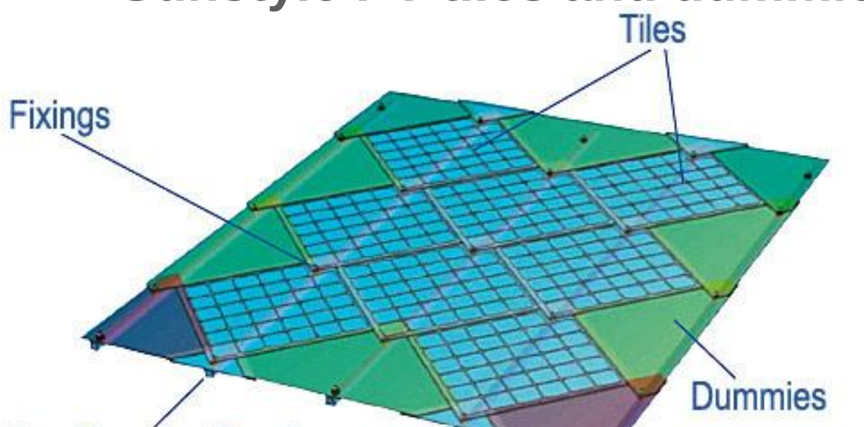
Examples of specifically designed BIPV products

- **Various shapes : Luxol tiles**



Examples of specifically designed BIPV products

- **Sunstyle PV tiles and dummies**



Benchmarking of complete PV roofs at CEA-INES

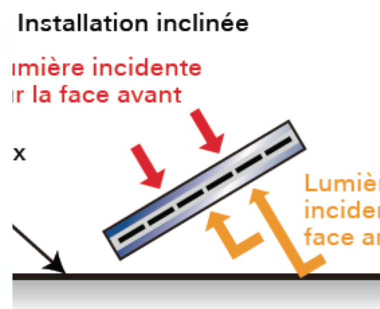
Avancis Photowatt

Luxol Solar Century

- **Aesthetic differences are more or less visible according to the incidence angle**

Integration with flexible membranes

Bifaciality for :



- Flat roofs
- Railings, fences, balconies,etc.

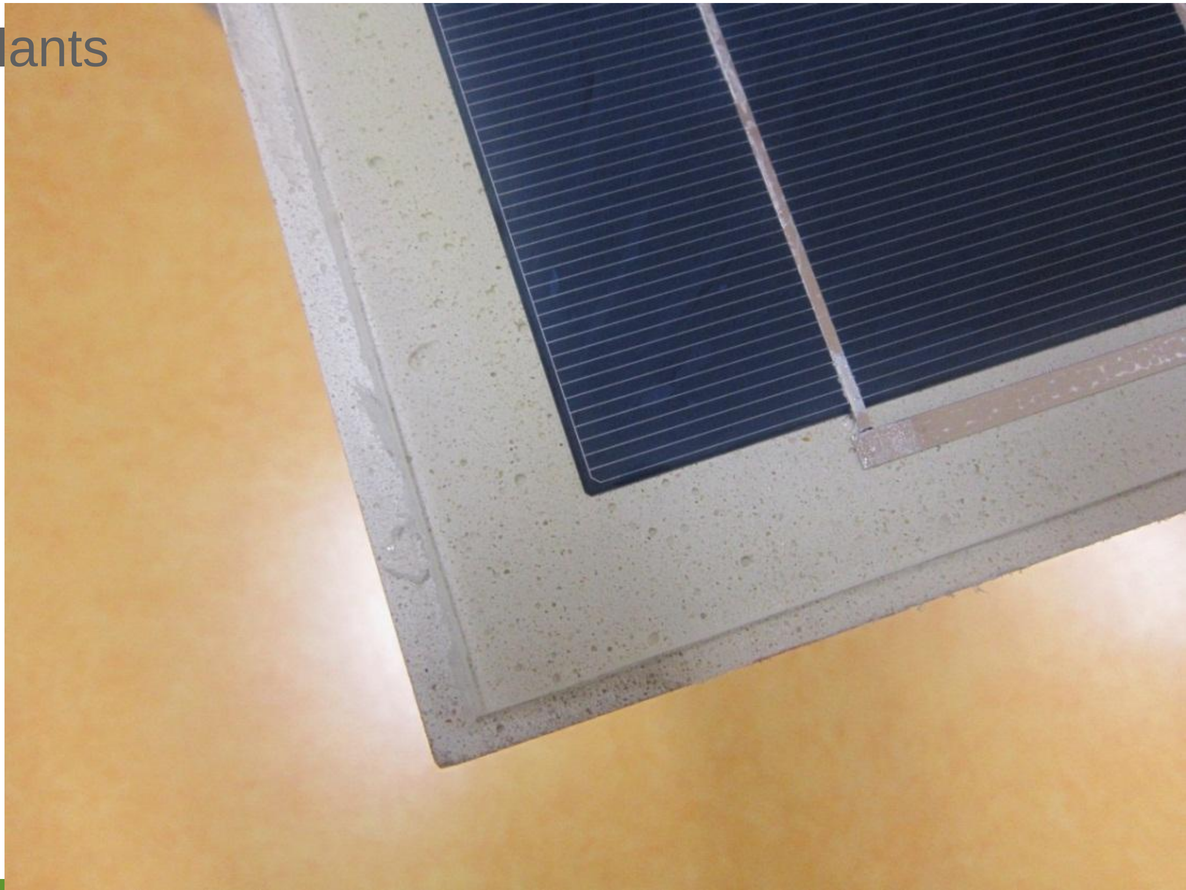
Solar protection applications

Transportation applications

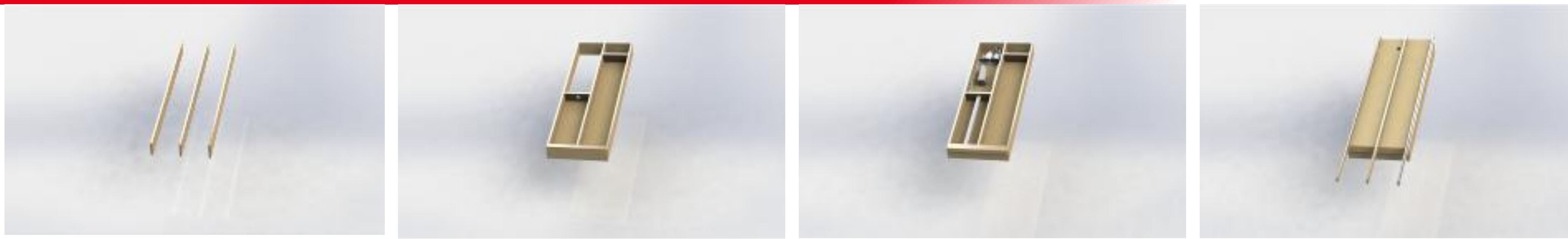
The parking area of one car (15m²) supplies enough electricity to drive > 12000 km a year

Development of specific products

- **Various materials: PV cells directly laminated on concrete structures (slabs, balconies) :**
  - with specific shapes
  - with specific encapsulants



PREFABRICATED COMPONENTS



Design of an industrialized Active Roof « all in one » :

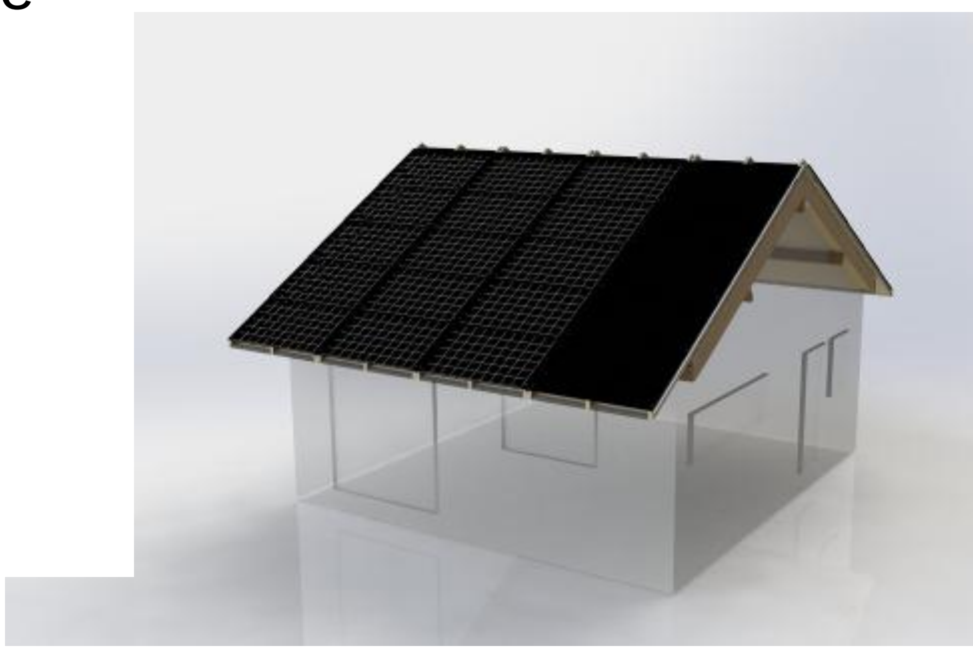
-Waterproofness

-Thermal Insulation

-Air pre-heating and ventilation

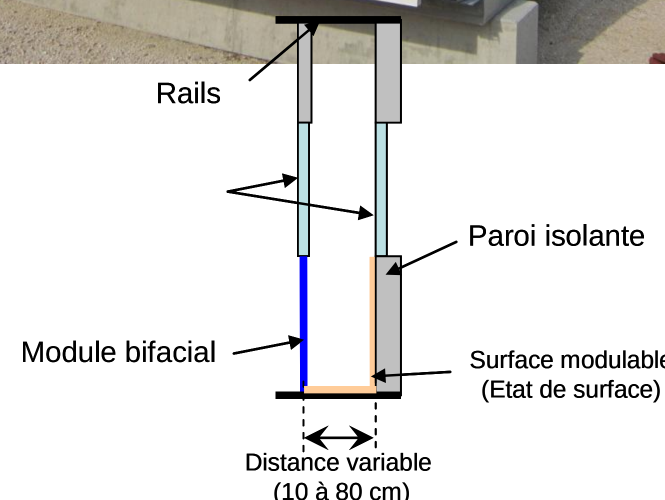
-Hot water production

-Photovoltaic power production



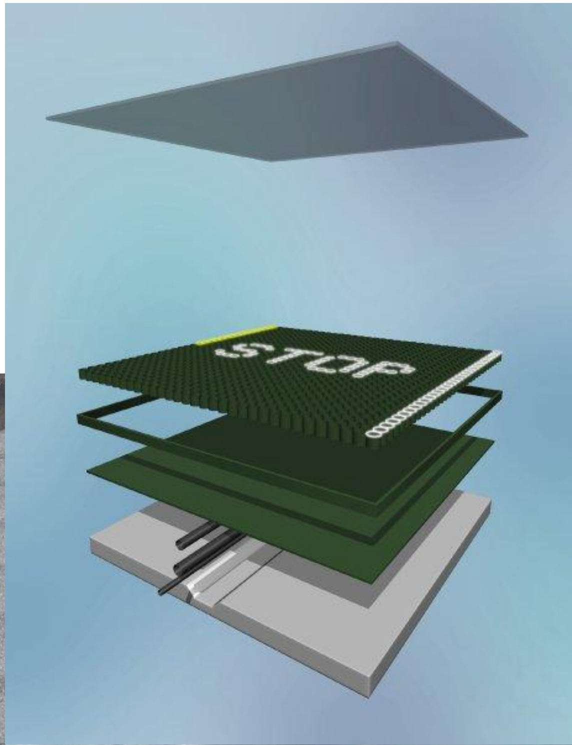
Bifacial cells in a double layer façade

- **Optimisation of several parameters :**
  - cell spacing
  - Distance between the two layers
  - Coatings of the second layer



Various shapes with specific requirements

- Sidewalks, parking lots, streets, roads :
- www.solarroads.com
- Various criteria :
  - Heavy loads (trucks, stones, bricks, etc.)
  - Roughness to provide high traction
  - Translucent coating : >90%
  - Weatherproof wiring and connections
  - Electrical design of a linear power plant



Various shapes with specific requirements

- No land usage, no impact on water usage and quality
- Development of non-metallic structures
- Possibility of cooling the PV modules

www.ciel-et-terre.net

1MW/km

CONCLUSIONS

The main trends to further advance on the PV module learning curve for the next two decades are there:

- Less material, less consumables
- Cheaper materials
- Higher efficiencies
- Cheaper high-throughput processes

Regarding the system learning curve :

- Higher efficiencies of all components
- Strongly decreasing installation costs due to smart integration in products and other systems (while increasing local content)

Thank you for your attention