RESILEX WEBINAR #2 : 20th January 2025

Solving the indium challenge for sustainable silicon heterojunction solar cells

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CEA, INES

CEA, scientific and technology research key player

CEA is a key research player, at the service of the French state, economy and citizen.

Based on an excellent fundamental research, CEA brings solutions in four main domains:

Low Carbon Energy (nuclear and renewable)

Digital

Future Healthcare

Defence and Security

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Low Carbon Energy
(nuclear and renewable)

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Research Institute for Energy Transition

Our mission since 20 years

Developing **cutting-edge technologies** to reach **carbon neutrality by 2050**, **empowering industries** and **catalyzing value** and **job creation** across France and Europe

Liten, a leader in the research for the energy transition

Employees
1000

Budget
160 M€

Industrial partners
+ 200

12
Platforms

~ 2 000
Patent portfolio

Grenoble GIANT Campus

Chambéry INES Campus

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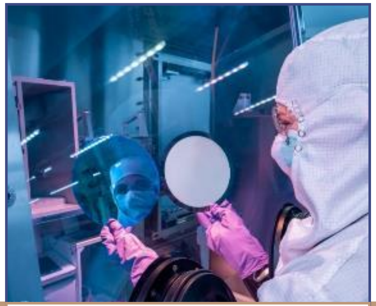
Strategic Research Areas

Photovoltaics



Batteries

Hydrogen, e-fuel & e-molecules

Systems, grids & energy efficiency

Materials & Circular economy

Zoom on the Solar Platform

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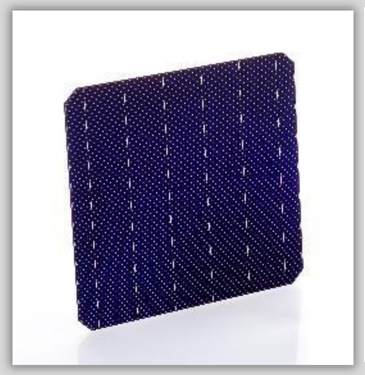
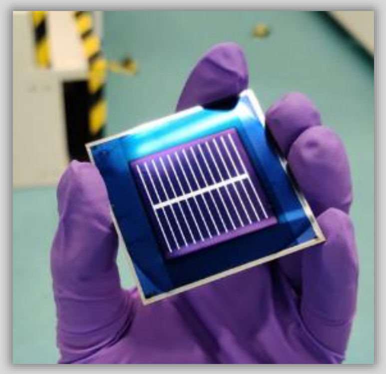
High efficiency PV technologies developed by **CEA at INES**



Heterojunction (SHJ) & TOPCon

25% efficiency
▶ to industry

- Industrialisation towards Gigafactories
- Sustainability : Indium, Silver…



TANDEM Si/Perovskite

29.8% on 9 cm²
▶ 30% on large format

- Efficiency
- Stability & Processes

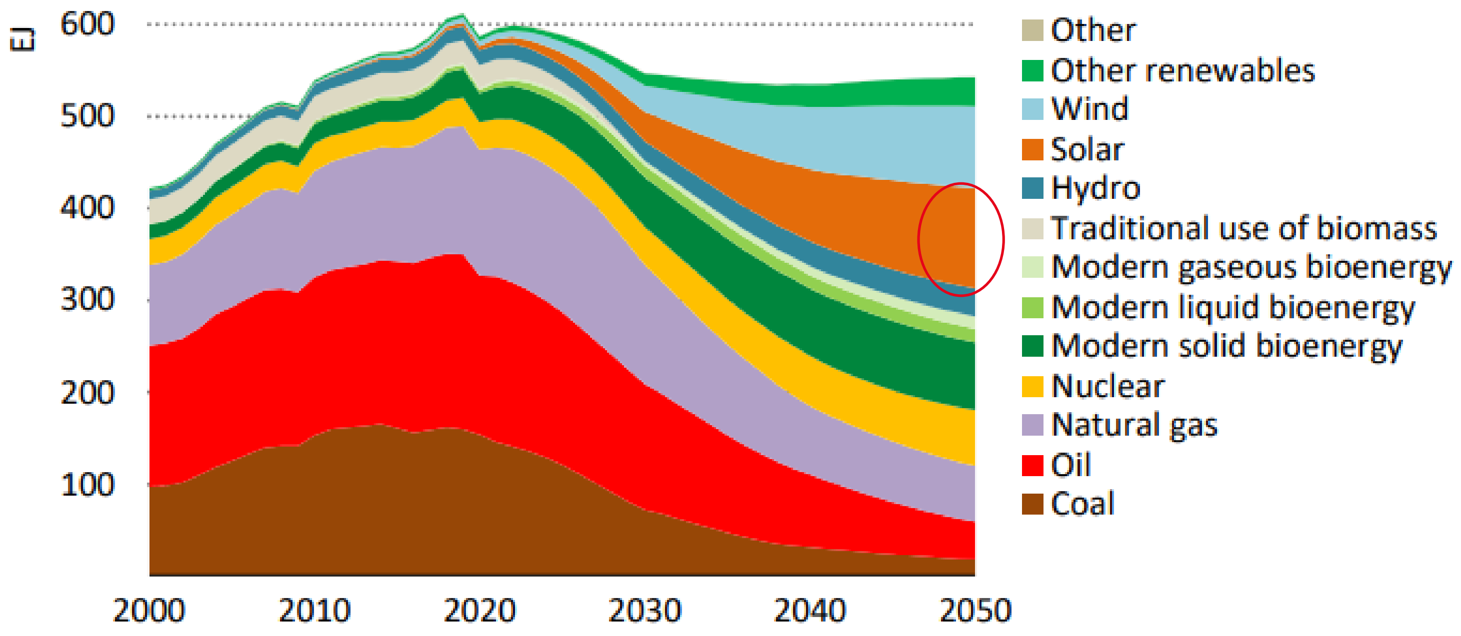
Advanced and eco-designed moduling

- Shingling, paving
- Interconnection
- Ecodesign : new material

Which place for PV in the world in 2050?

Roadmap for energy supply…

Total energy supply in the NZE



Net zero CO_2 roadmap from IEA,
push to **massive electrification of energy source**
from **20% to 50%** of the final energy use

… and corresponding solar PV installed capacity

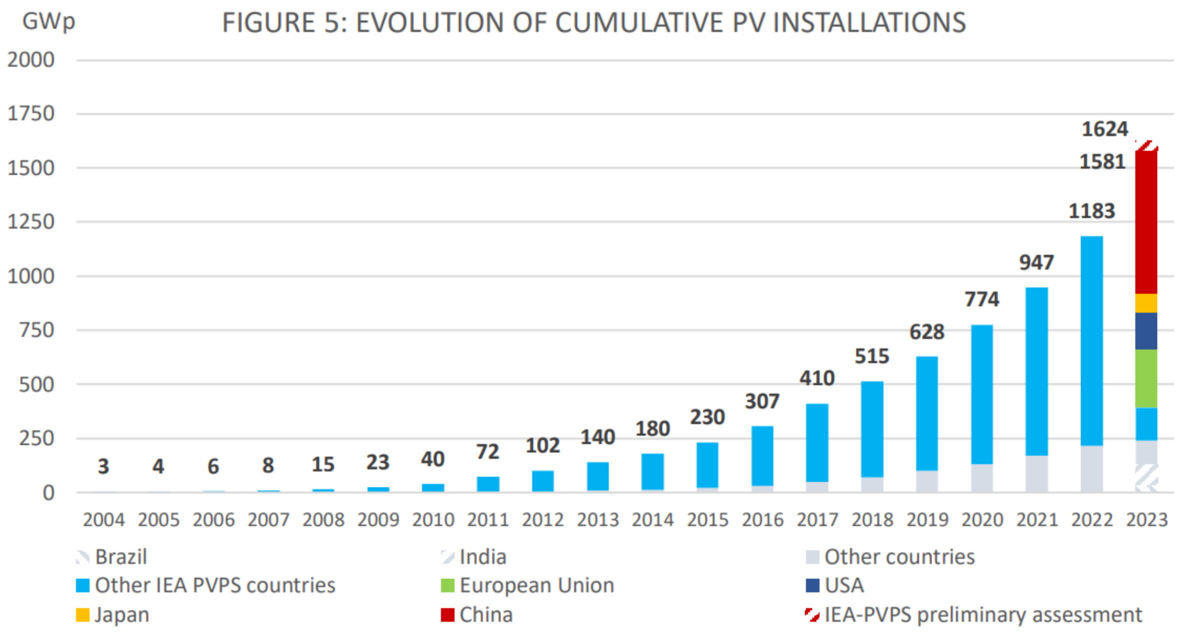
Low scenario from IEA:
14.4 TW of installed capacity

High scenario from ITRPV:
63.4 TW of installed capacity

Source : Net Zero by 2050 – A Roadmap for the Global Energy Sector – IEA (revised 2021) // 15th edition International Technology Roadmap for PV on 2023 results (2024)

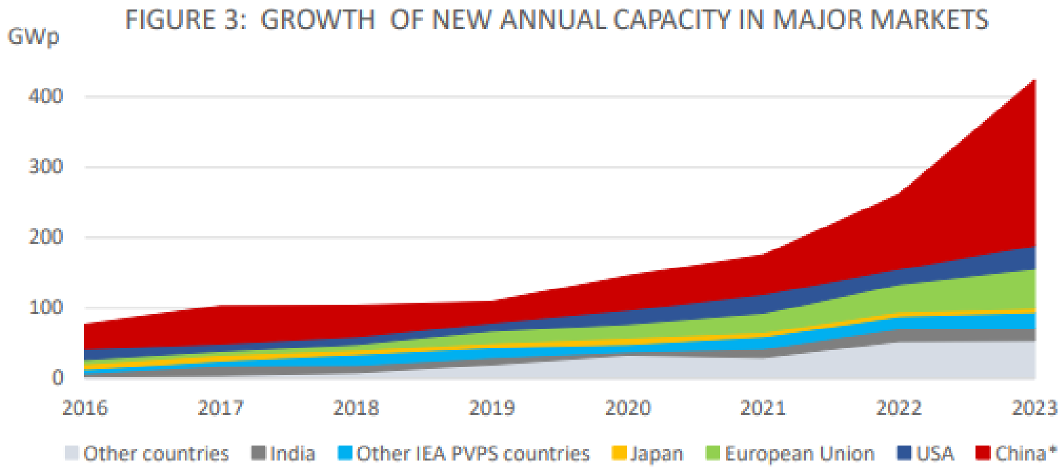
What was the situation in 2023?

Current total installed capacity



- **1.6 TW** of installed capacity mainly in china

Annual capacity growth



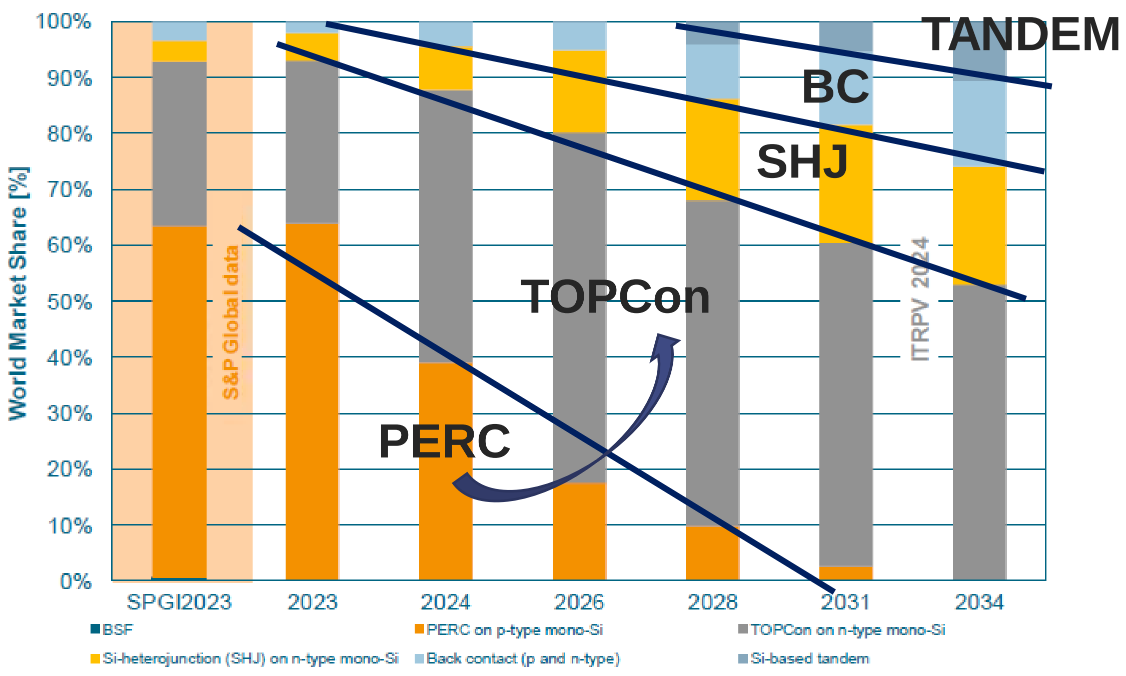
- Important dynamic during the last year
- Additional growth of 210 GW in 2023
- UE 20% of the market

Targeted production capacity:
Low scenario: +600 GW/year
High scenario: +2300 GW/year

Source : IEA Photovoltaic power systems programme – Snapshot of Global PV Markets (2024)

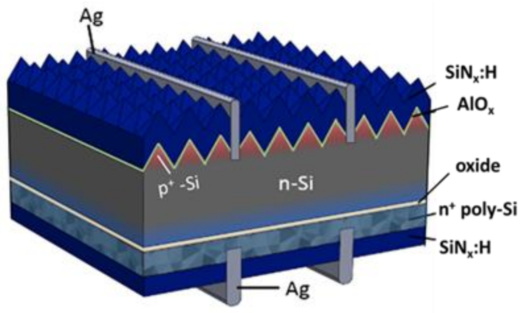
PV solar cell technologies

Technology market share



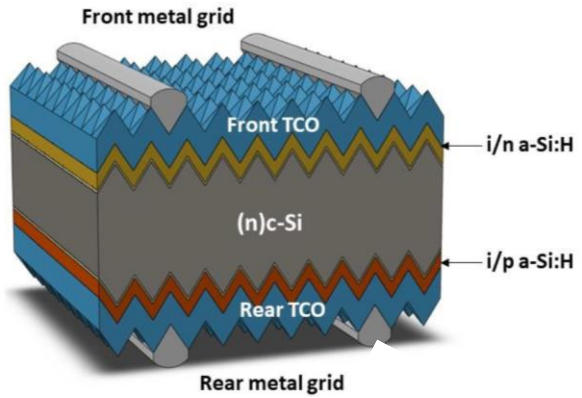
- **Silicon based technologies** dominate the market
- **PERC** manufacturers switch to **TOPCON technology**
- Market share of **SHJ** should increase from **<u>5% to 20%</u>**
- Tandem foreseen as next step

Source : 15th edition International Technology Roadmap for PV on 2023 results (2024)



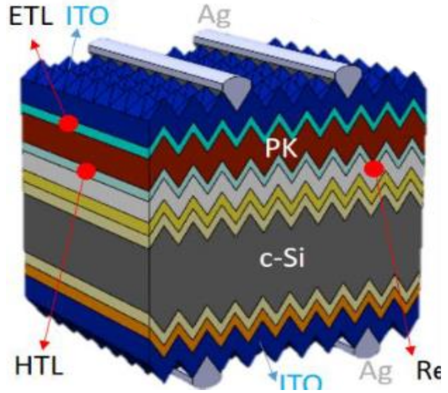
<u>TOPCON</u>

>26%, high TRL



<u>Heterojunction (SHJ)</u>

>26%, high TRL

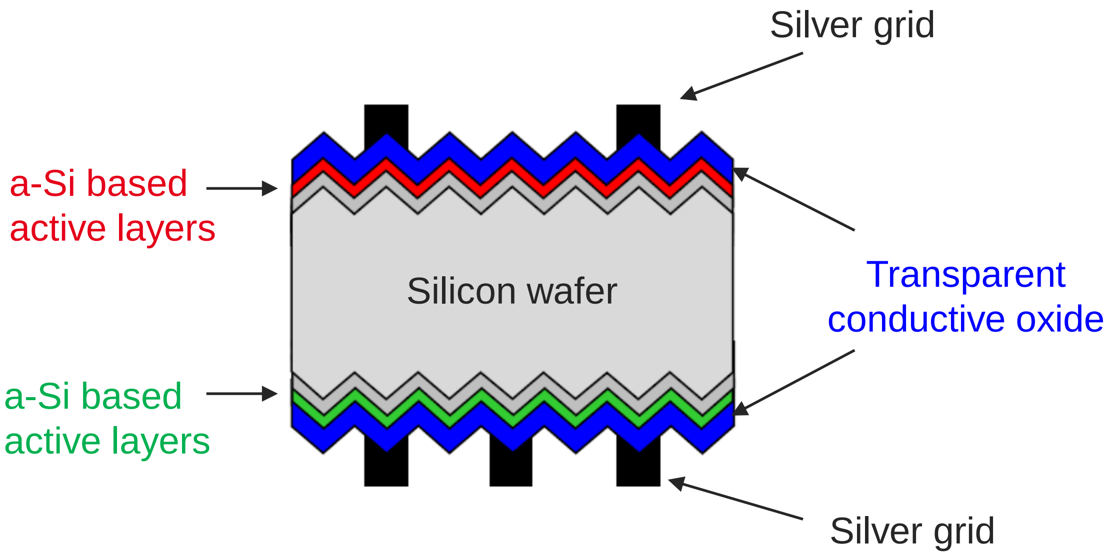


<u>Tandem (2T,3T,…)</u>

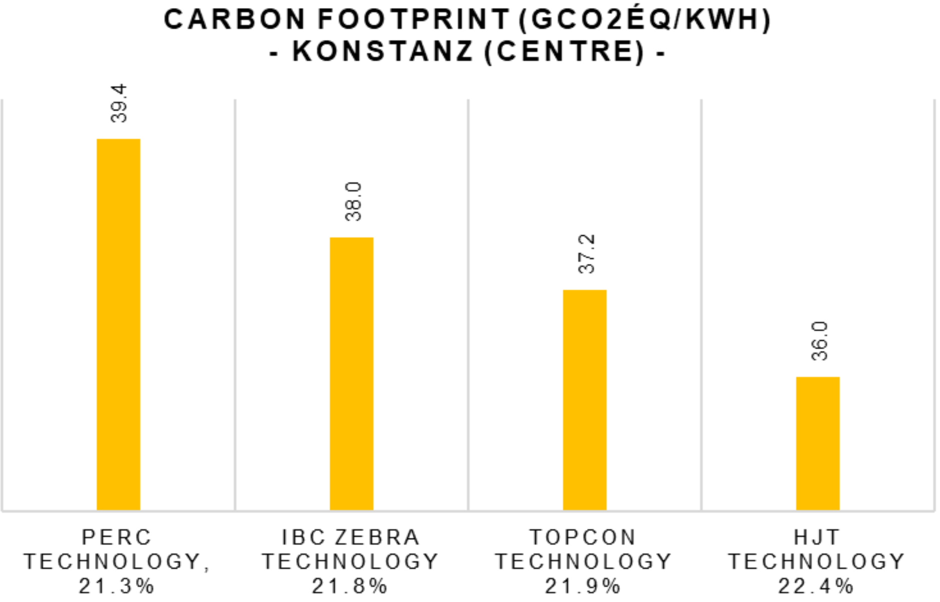
>35% low TRL

Silicon SHJ technology

SHJ cell structure



Carbon footprint by technology



Pros

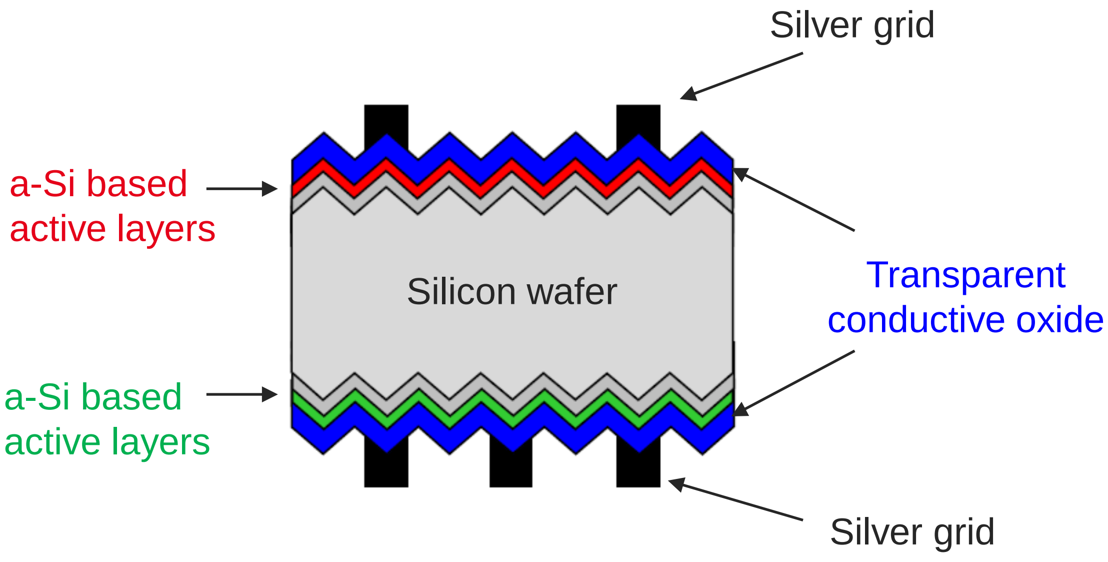
- High performance (V_{oc} > 750 mV), efficiency record > 26%
- High bifaciality (> 90%)
- Low temperature process > 200°C with few steps

Low carbon footprint potential

Source : Libal, J., Gazbour, N., n.d. Cost of ownership of n-type silicon solar cells and modules and life cycle analysis. N-Type Cryst. Silicon Photovolt., Books 253–280.

Silicon SHJ technology

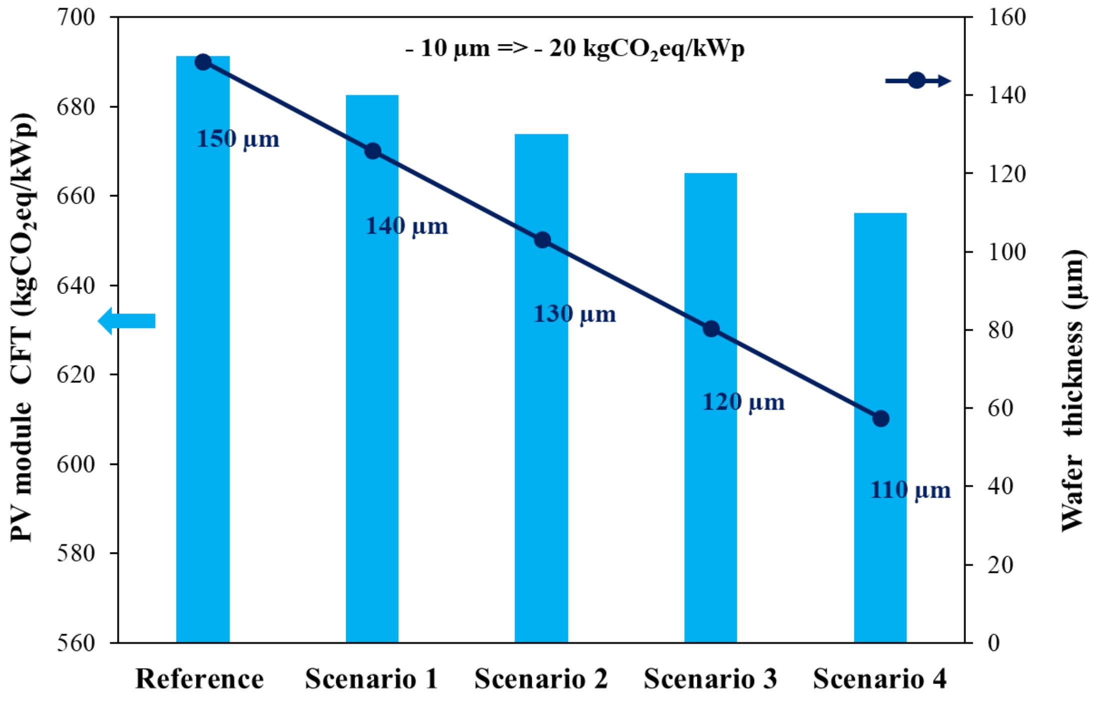
SHJ cell structure



Pros

- High performance (V_{oc} > 750 mV), efficiency record > 26%
- High bifaciality (> 90%)
- Low temperature process > 200°C with few steps
- Compatible with thin wafers (< 90 µm)
- …

Impact of the wafer thickness on the Carbon footprint

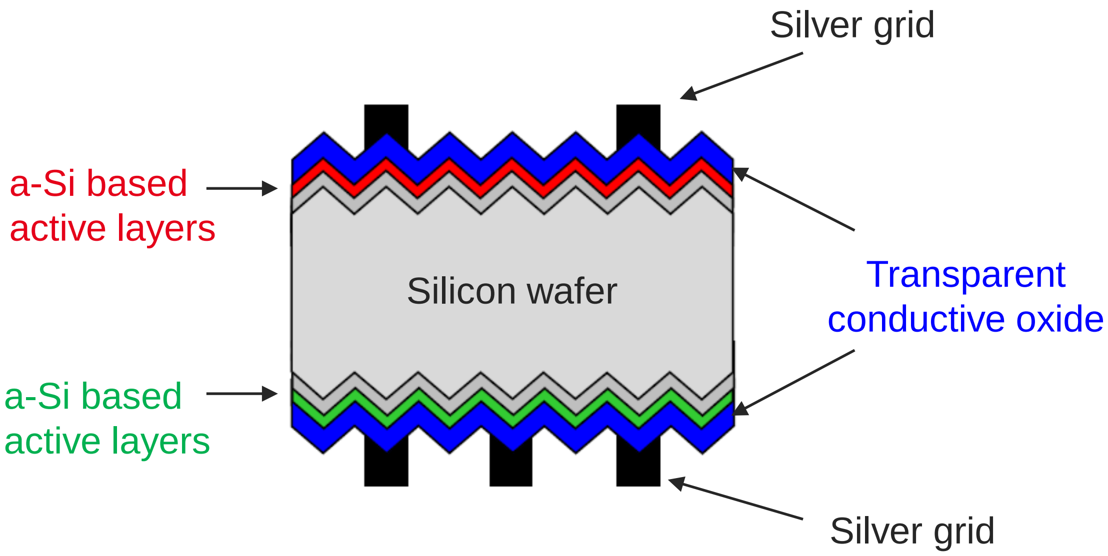


Reducing the wafer thickness by **10 µm** lower the carbon footprint by **20 $kgCO_2eq/kWp$**

Source : N. Gazbour et al. Presented at SiliconPV 2024

Silicon SHJ technology

SHJ cell structure



→ Promising technology for low environmental footprint and reduced silicon consumption

Cons

- Technology using a **larger quantity of silver**
(due to the lower conductivity of the silver paste dedicated to low temperature process) → High cost

- Structure that needs a transparent conductive oxide (TCO) based on **indium oxide**

Pros

- High performance (V_{oc} > 750 mV), efficiency record > 26%
- High bifaciality (> 90%)
- Low temperature process > 200°C with few steps
- Compatible with thin wafers (< 90 µm)
- …

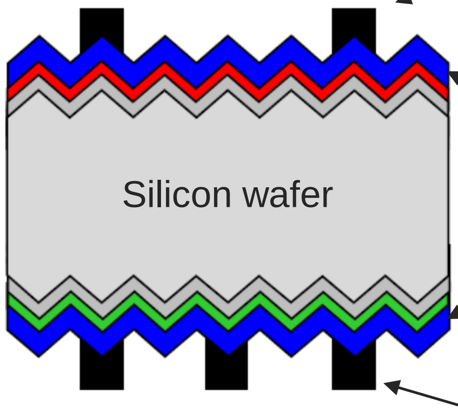
Develop sustainable and eco-designed photovoltaic solar cells & module

- Drastic reduction of CRM
- In-free and Ag-free SHJ

Source :

Why do we need Indium?

SHJ cell structure



Transparent conductive oxide (TCO) requirements:

- Efficient charge transport to metal grid → **high conductivity**
- **Low contact resistance** with metal grids and active layers

- High transmittance (**T>80%** between 300-1200nm)
- Efficient antireflective layer (drive the layer thicknesses)

- Good stability under humidity and UV exposure

Provided by In-rich materials

→ Mainstream = 100 nm **indium tin oxide (ITO)** on both side

Source :

Indium challenge for sustainable SHJ cells

Supply

- 900 tons/year from primary production
- 1100 tons/year from secondary production

➔ **≈ 2000 tons/year**

Table 5. Refinery supply of indium to the market according to the USGS Minerals Yearbook 2021 (Tolcin, 2013, 2015, 2022; Anderson 2022) and the British Geological Survey (*) (Idoine et al., 2022)

Country	2017	2018	2019	2020	2021	2020*
China	478	483	534	540	540	500
South Korea	225	235	225	210	190	100
Japan	70	70	70	66	66	70
Canada	67	65	63	66	60	61
France	30	46	40	38	38	40
Belgium	20	22	20	20	20	20
Peru	10	11	12	12	12	10
Russia	5	5	5	5	5	7
Uzbekistan	1.1	0.8	1	1	1	1
Other	10	10	10	10	10	15
Total	916	948	980	968	942	894

Amounts in tons indium per year

Lifecycle

- **By product** from other metal ores
- 65% of the market dedicated to touch screen/display/LED

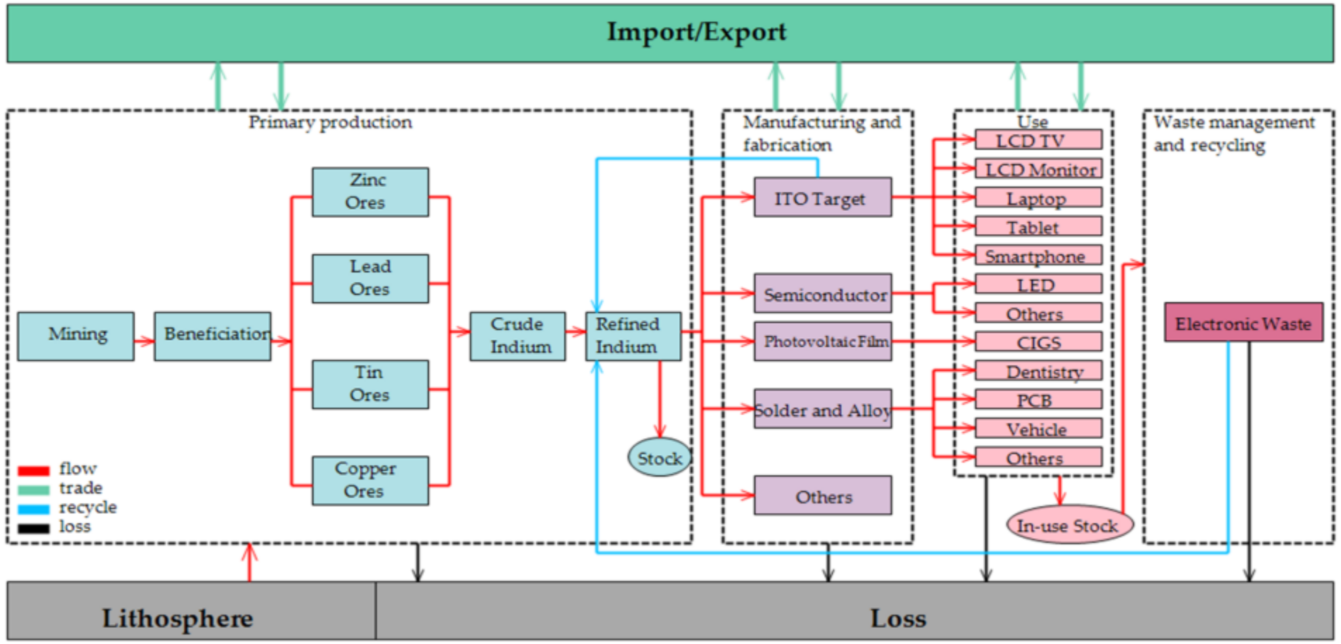


Figure 1. Framework of indium flow in China mainland.

➡ Limited production
Competition with high value-added technologies

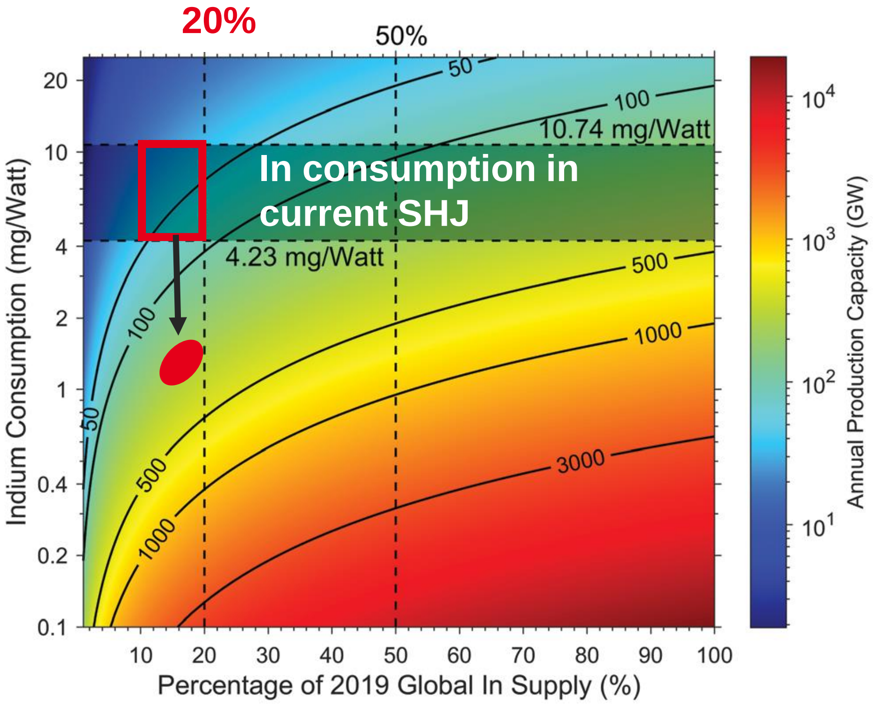
Sources : Sverdrup2024, Modeling Indium Extraction, Supply, Price, Use and Recycling 1930–2200 Using the WORLD7 Model: Implication for the Imaginaries of Sustainable Europe 2050 // Lin2021, How Can China's Indium Resources Have a Sustainable Future? Research Based on the Industry Chain

Indium challenge for sustainable SHJ cells

Consumption for PV:

Standard SHJ structure uses 100 nm of TCO on both side → **4,23-6,26 mg/Watt** on cells*

** Area = 210x210 mm², η=25,11%*



Production capacity limited below 100 GW/year

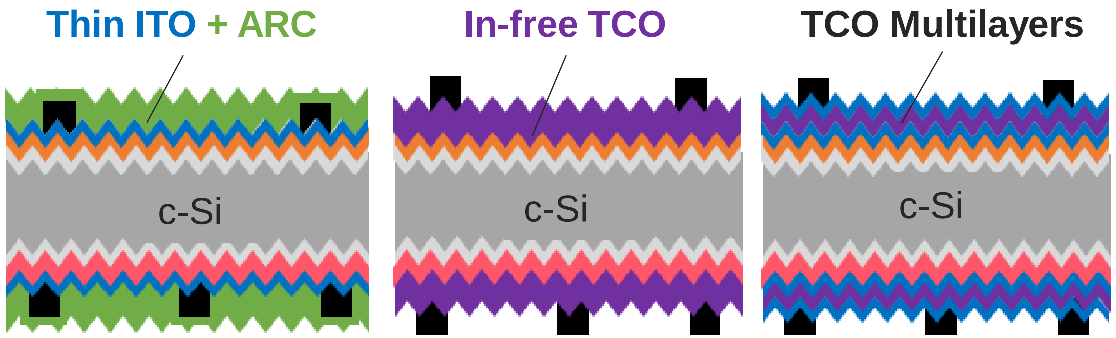
→ To reach the targeted annual production**, the indium consumption for SHJ cells must be reduced by ~70%**

Approaches to reduce Indium

- Thin In-based layers combined with an ARC layer (SiN_x:H, SiO_x:H, …)

→ **DARC solution**

- **Indium-free TCO** (AZO, SnO_2…)
- **Multilayers** of In-free and In-based materials



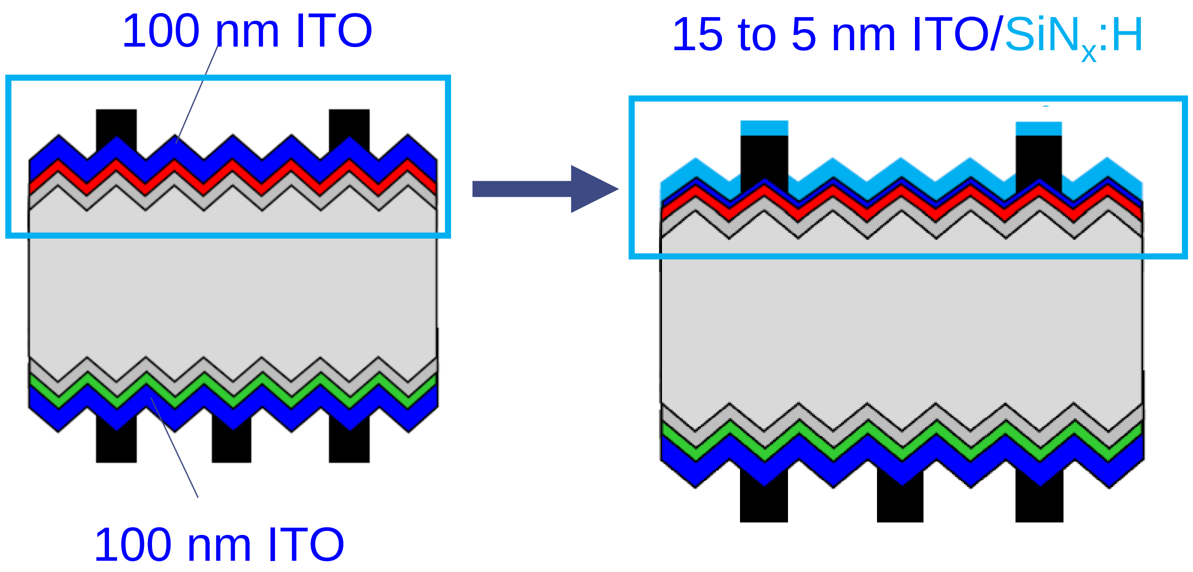
Sources : Zhang 2021, Design considerations for multi-terawatt scale manufacturing of existing and future photovoltaic

Solutions developed at CEA in the RESILEX project
Focus on thin Indium-based TCO

RESILEX objectives:

- Indium reduction > 70%
- Similar efficiency
- No impact on the reliability

Reference SHJ:



Front side approach:

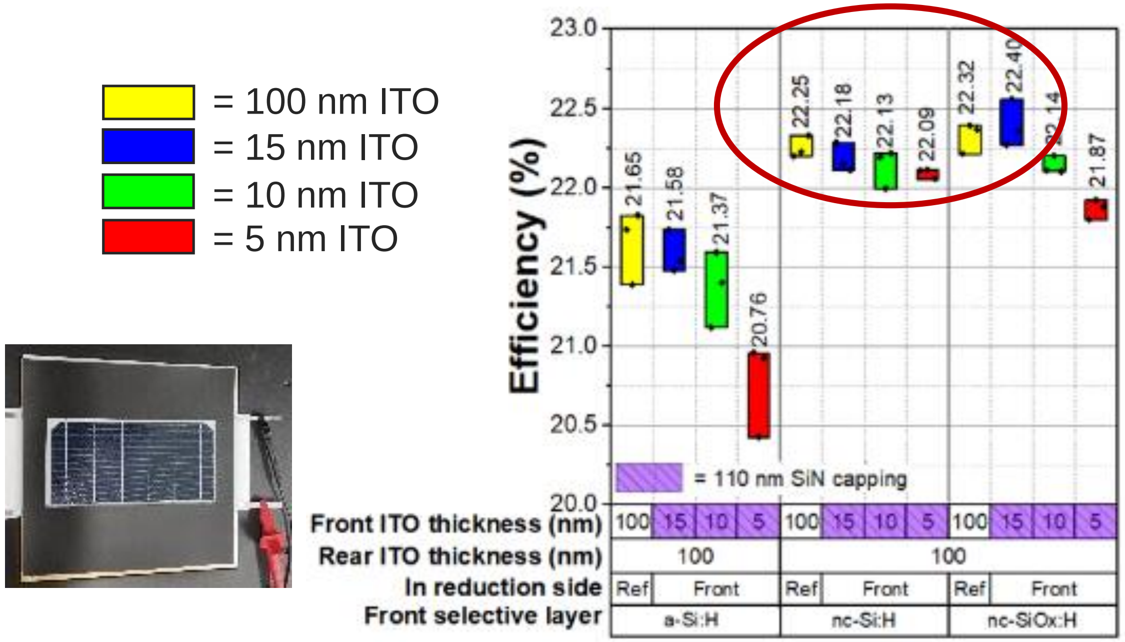
Ultra-thin ITO layers + double-antireflective layer

- Development of highly conductive thin ITO layers down to 15 - 5 nm
- Modification of the under active layers to reduce the requirements (a-Si:H/ nc-Si:H / nc-SiOx:H)
- Validate the module interconnection of the bilayer approach with SiN_x

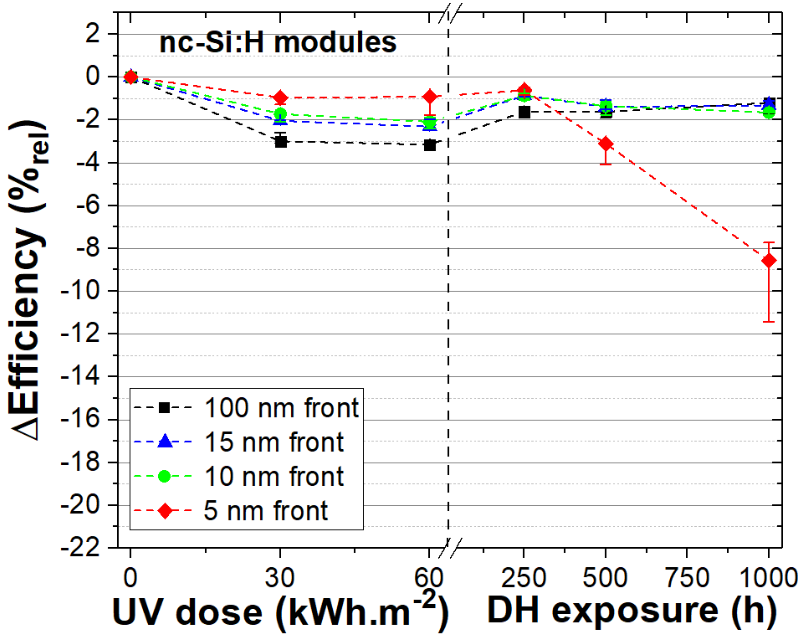
Sources : T. Gageot, et al., Sol. Energy Mater. & Sol. Cells , Vol. 261, 2023, 112512

Solutions developed at CEA in the RESILEX project
Focus on thin Indium-based TCO

Results after module integration:



Module reliability under UV and humidity (DH) tests:



- Similar efficiency than reference for thin ITO combined with modified active layers
- Enhanced UV reliability for modules with ultrathin ITOs
- 5 nm of ITO is unstable under humidity

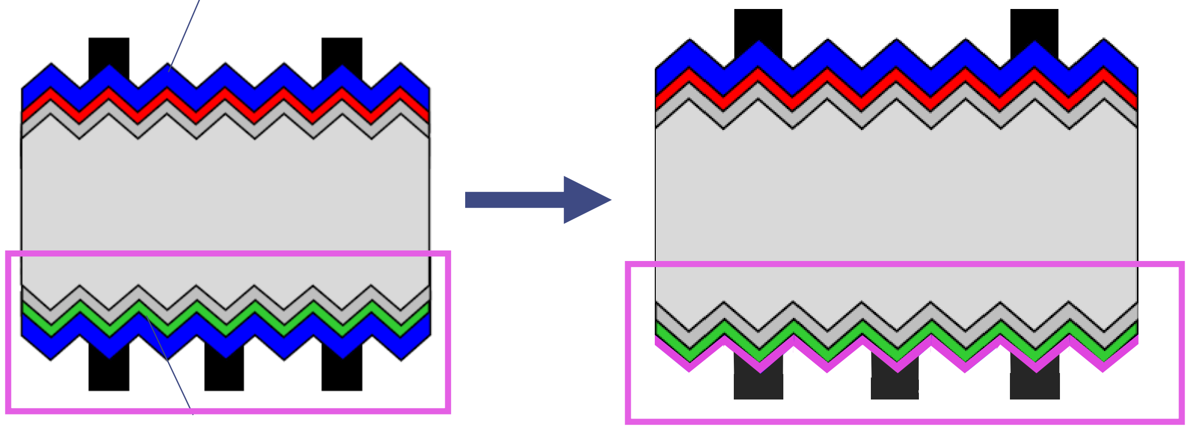
Sources : T. Gageot, et al., Sol. Energy Mater. & Sol. Cells , Vol. 261, 2023, 112512

Solutions developed at CEA in the RESILEX project
Focus on thin Indium-based TCO

RESILEX objectives:
- Indium reduction > 70%
- Similar efficiency
- No impact on the reliability

Reference SHJ:

100 nm ITO



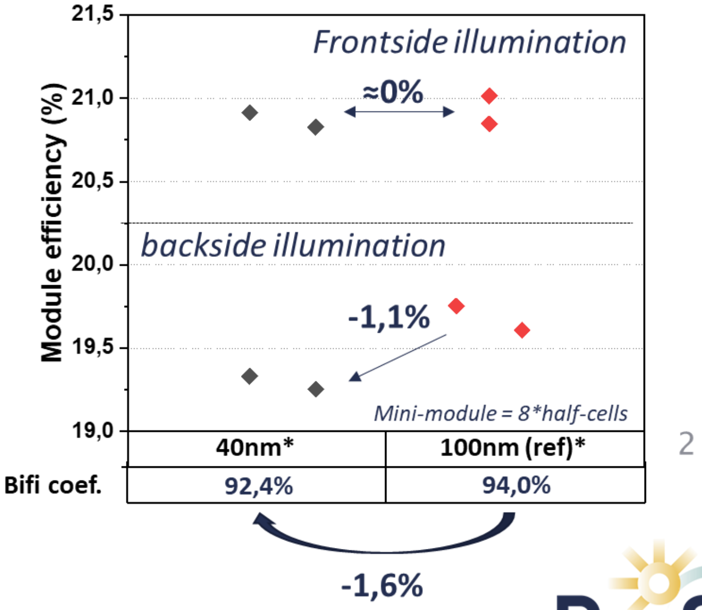
100 nm ITO
100 nm IMO:H

40 nm IMO:H

Rear approach & results:

Reduction of Indium-based TCO layer [11]

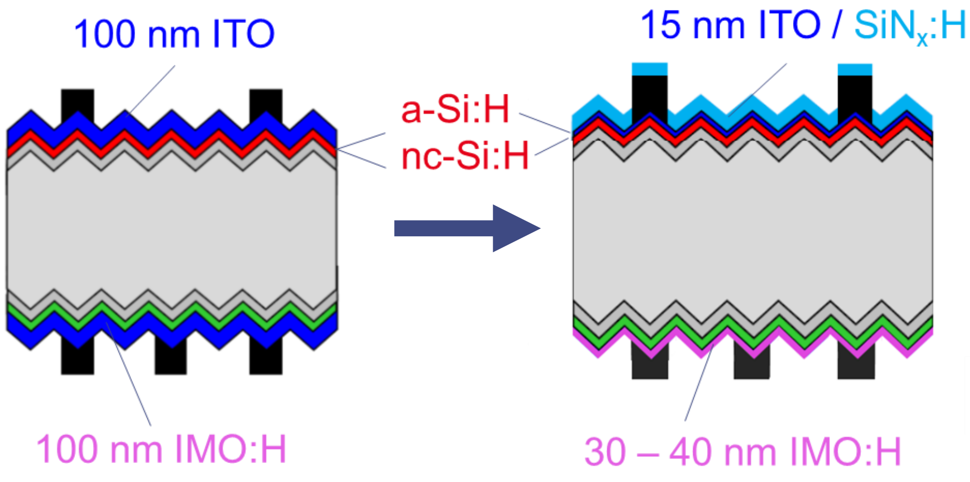
- Work on hydrogenated indium metal oxide (IMO:H)
- Thickness reduced by 60% without impact on module efficiency
- **Reduction of the bifaciality coefficient**



Sources : W. Favre, PVSEC Asia 33, November 17th, 2022, Nagoya

Solutions developed at CEA in the RESILEX project

Combination of front & rear approach:



SHJ cells with In reduction :
- **72.1%** (IMO:H 40 nm)
- **77.2%** (IMO:H 30 nm)

Solar cells median I(V) results:

(n) selective layer	ITO (nm)	IMO:H (nm)	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF (%)	Eff. (%)
a-Si:H	100	100	737.3	38.08	80.0	22.44
	15	40	736.2	38.19	79.0	22.19
		30	735.2	38.27	78.3	22.04
nc-Si:H*	100	100	737.4	38.22	80.1	22.52
	15	40	736.7	38.23	79.6	22.38
		30	736.5	38.26	79.5	22.36

Structure optimization

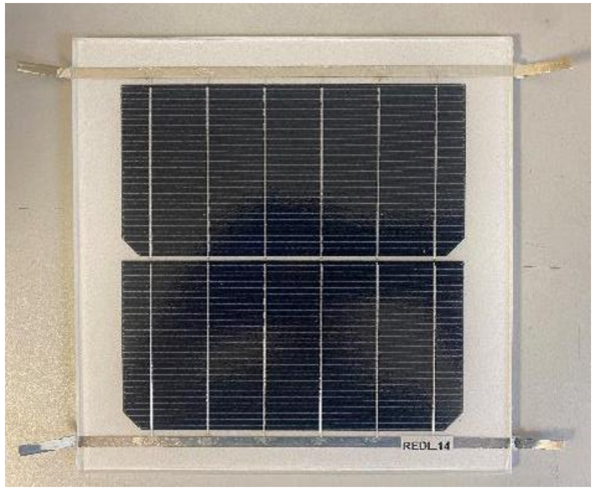
- Reduced resistance losses for the use of nc-Si:H
- **Efficiency loss < 0.16%$_{abs}$ for In reduction of 77.2%**

Sources : *Lanterne2024, Indium reduction above 70% in SHJ solar cells: Study of the module stability, silicon PV2024*

Solutions developed at CEA in the RESILEX project

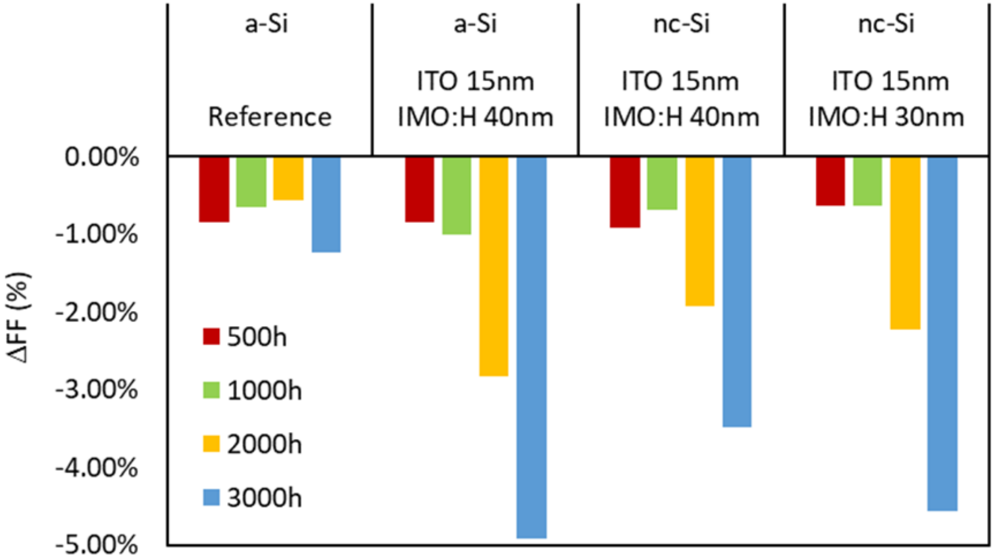
Module reliability of front + rear In reduction

Module structure:
- Two ½ cells,
- glass/glass module
- POE encapsulant
- 3 modules/split



Humidity Test (DH):
- 3000 h
- 85°C
- 85% relative humidity

In reduction 0% -72,1% -72,1% -77,2%

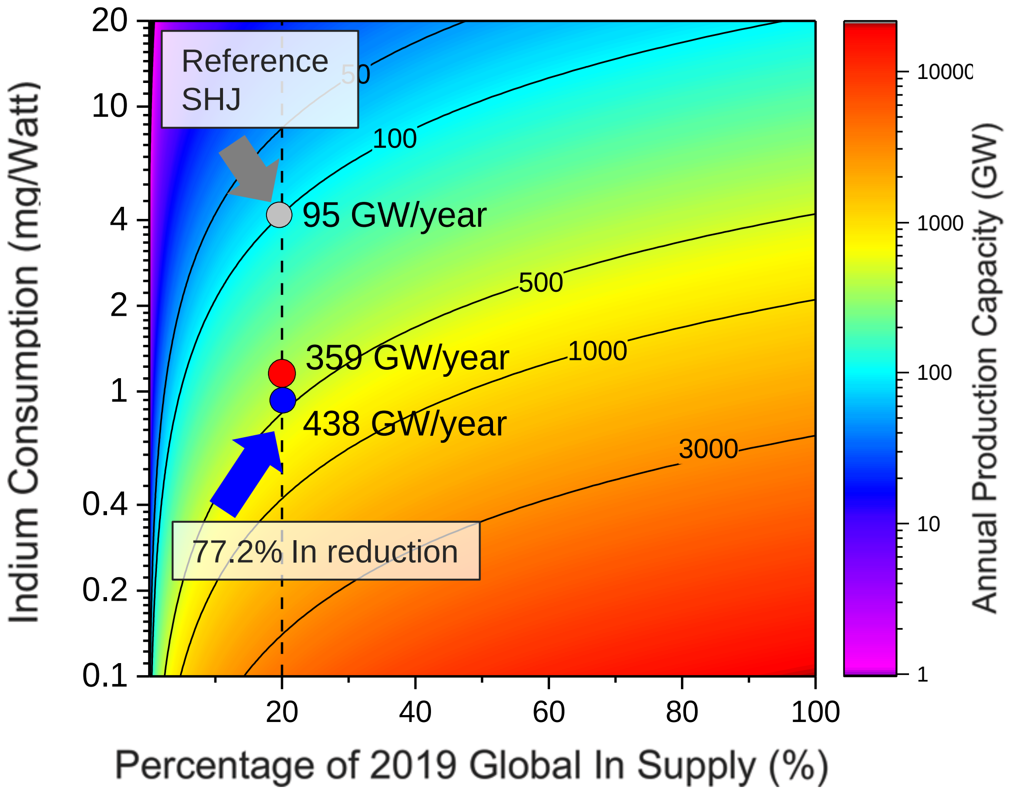


Results:
- Higher sensitivity to humidity for low-In SHJ modules after 2000 h
- **Low-In modules passed 3 times the standard**

(Power loss < 5% after 3000 h under humidity)

Sources : *Lanterne 2024, Indium reduction above 70% in SHJ solar cells: Study of the module stability, silicon PV2024*

Summary and next steps



= Reference (ITO 100 nm / IMO:H 100 nm)

= 72.1% In reduction (ITO 15 nm / IMO:H 40 nm)

= 77.2% In reduction (ITO 15 nm / IMO:H 30 nm)

- Possibility to reduce Indium content in SHJ up to 77.2% with very low impact on the cell efficiency was demonstrated
- Modules are more sensitive to humidity but pass 3 times the standard and are more stable under UV
- Possibility to increase the annual production capacity from 95 GW/year to 438 GW/year with these innovations
- The results must be confirmed in larger scale experiments

→ Other approaches are possible to reduce indium : In-free solutions under development in RESILEX

→ Next challenge is to combine this reduction with low silver or silver-free metallization

Sources : *T. Gageot PhD Thesis 2024*

Thank you!

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