RESILEX WEBINAR : 12th November 2025

From silicon waste to high-purity solar cells

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

Low Carbon Energy
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liten

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	Budget	Industrial partners	Platforms	Patent portfolio
1000	160 M€	+ 200	12	~ 2 000

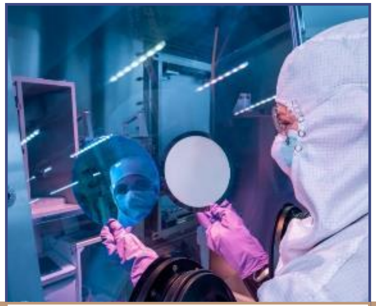
Grenoble GIANT Campus

Chambéry INES Campus

INES INSTITUT NATIONAL DE L'ENERGIE SOLAIRE

Strategic Research Areas

Photovoltaics



Batteries

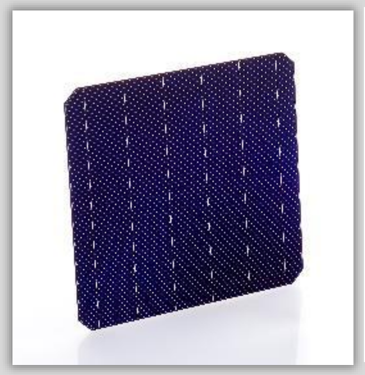
Hydrogen, e-fuel & e-molecules

Systems, grids & energy efficiency

Materials & Circular economy

Zoom on the Solar Platform

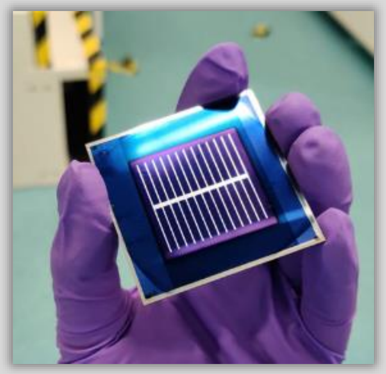
High efficiency PV technologies developed by **CEA at INES**



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

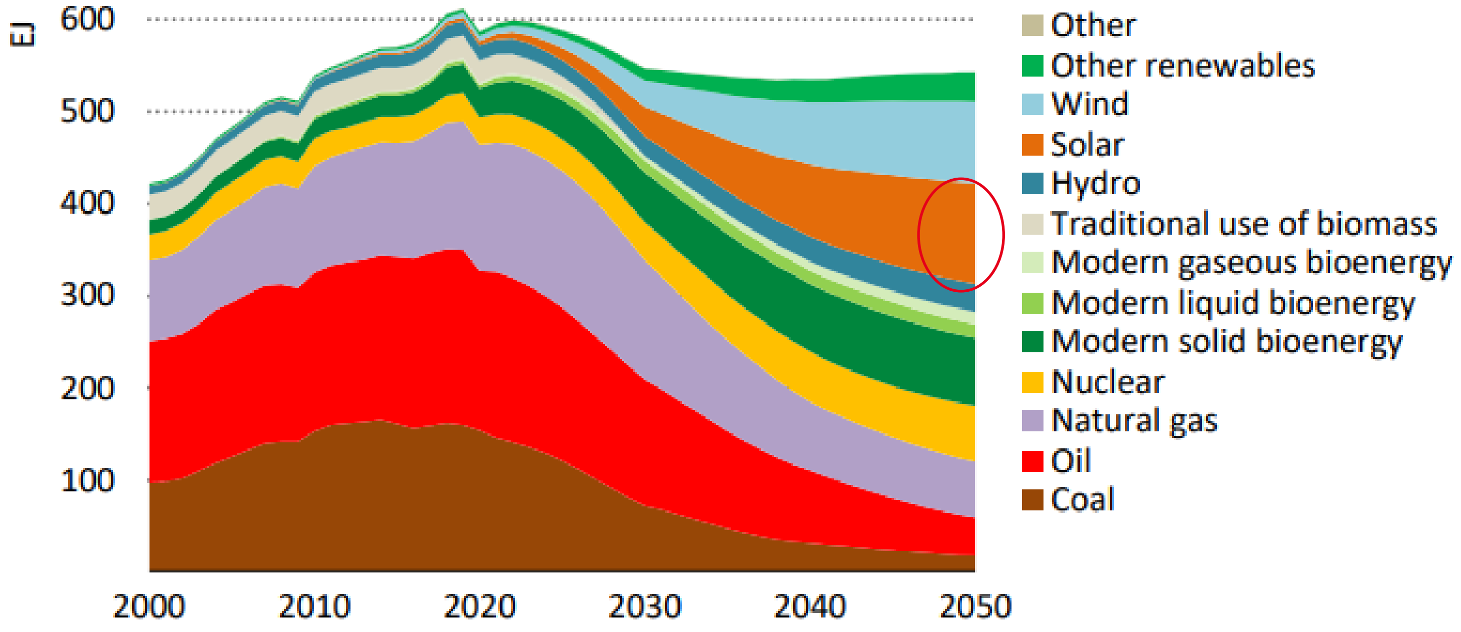
- Shingling, paving
- Interconnection
- Ecodesign : new material

PILOT LINE – 2400 cells/hour

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

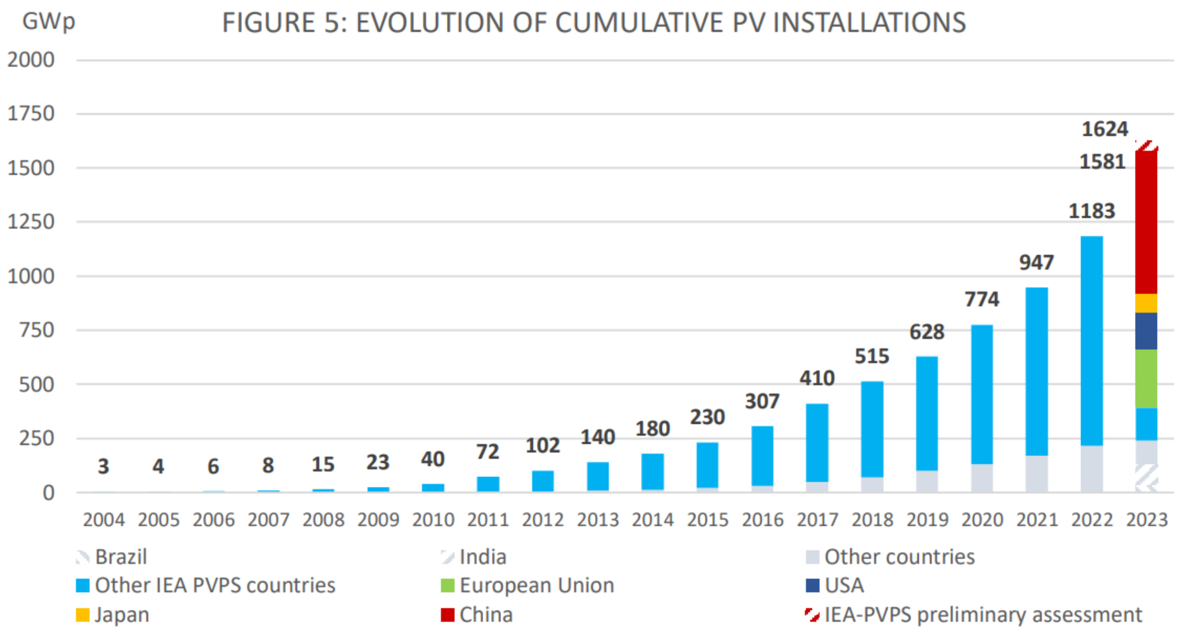
Low scenario from IEA:
14.4 TW of installed capacity

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)

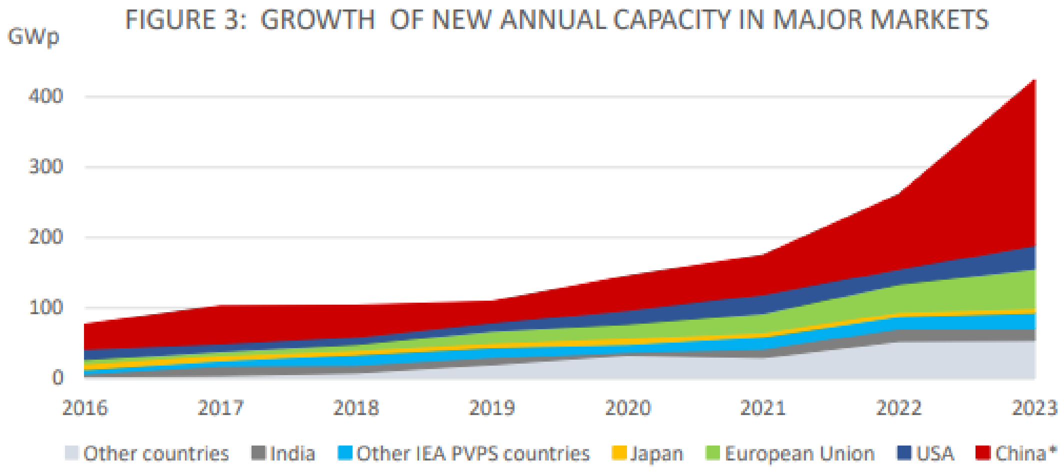
What was the situation in 2023?

Current total installed capacity



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

Annual capacity growth



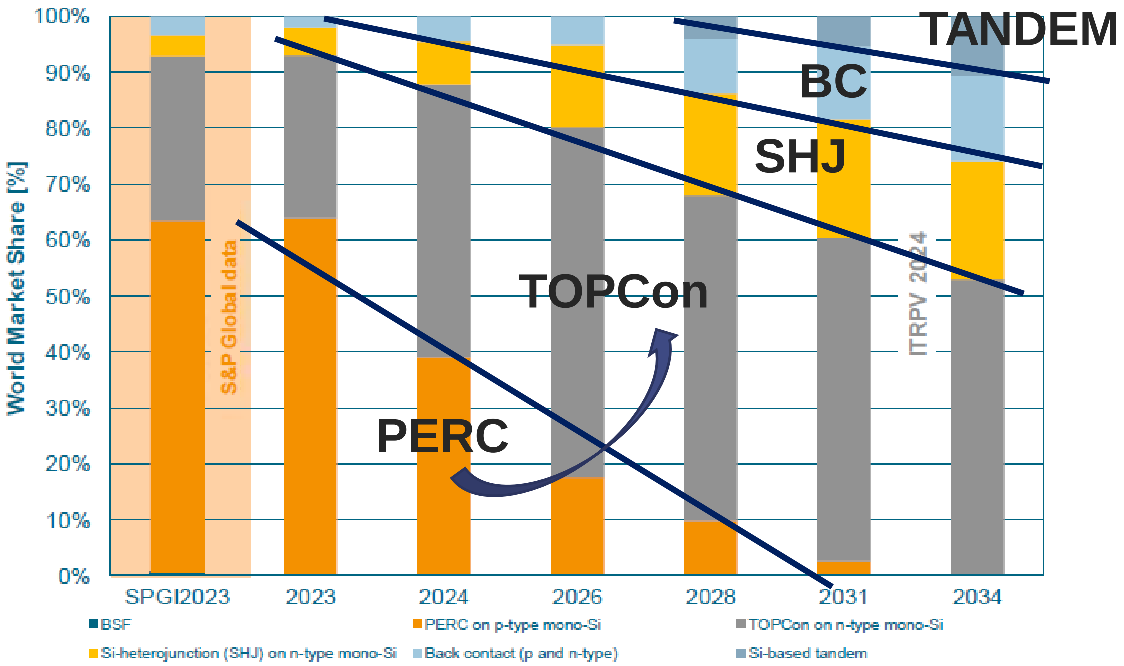
- Important dynamic during the last year
- Additional growth of 210 GW in 2023
- UE ~15% of the market

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

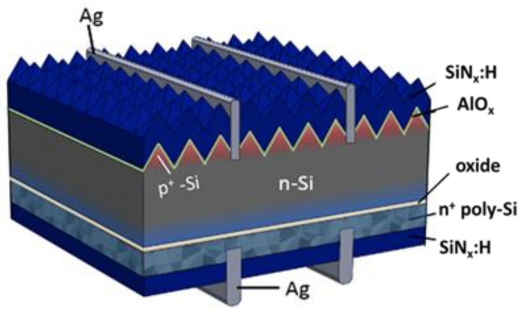
Source : IEA Photovoltaic power systems programme – Snapshot of Global PV Markets (2024)

PV solar cell technologies

Technology market share

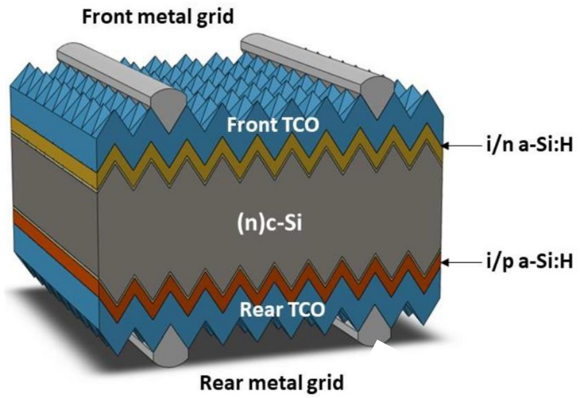


- **Silicon based technologies** dominate the market
- **PERC** manufacturers switch to **TOPCON technology**
- Market share of **SHJ** should increase from <u>**5% to 20%**</u>
- Tandem foreseen as next step



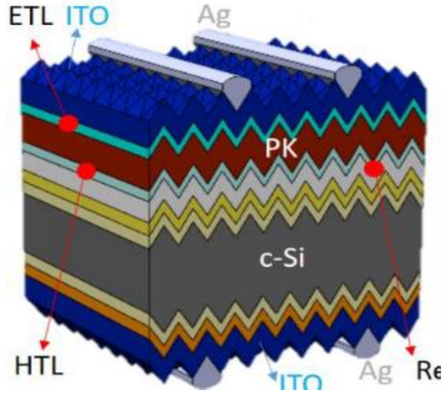
<u>TOPCON</u>

>26%, high TRL



<u>Heterojunction (SHJ)</u>

>26%, high TRL



<u>Tandem (2T,3T,…)</u>

>35% low TRL

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

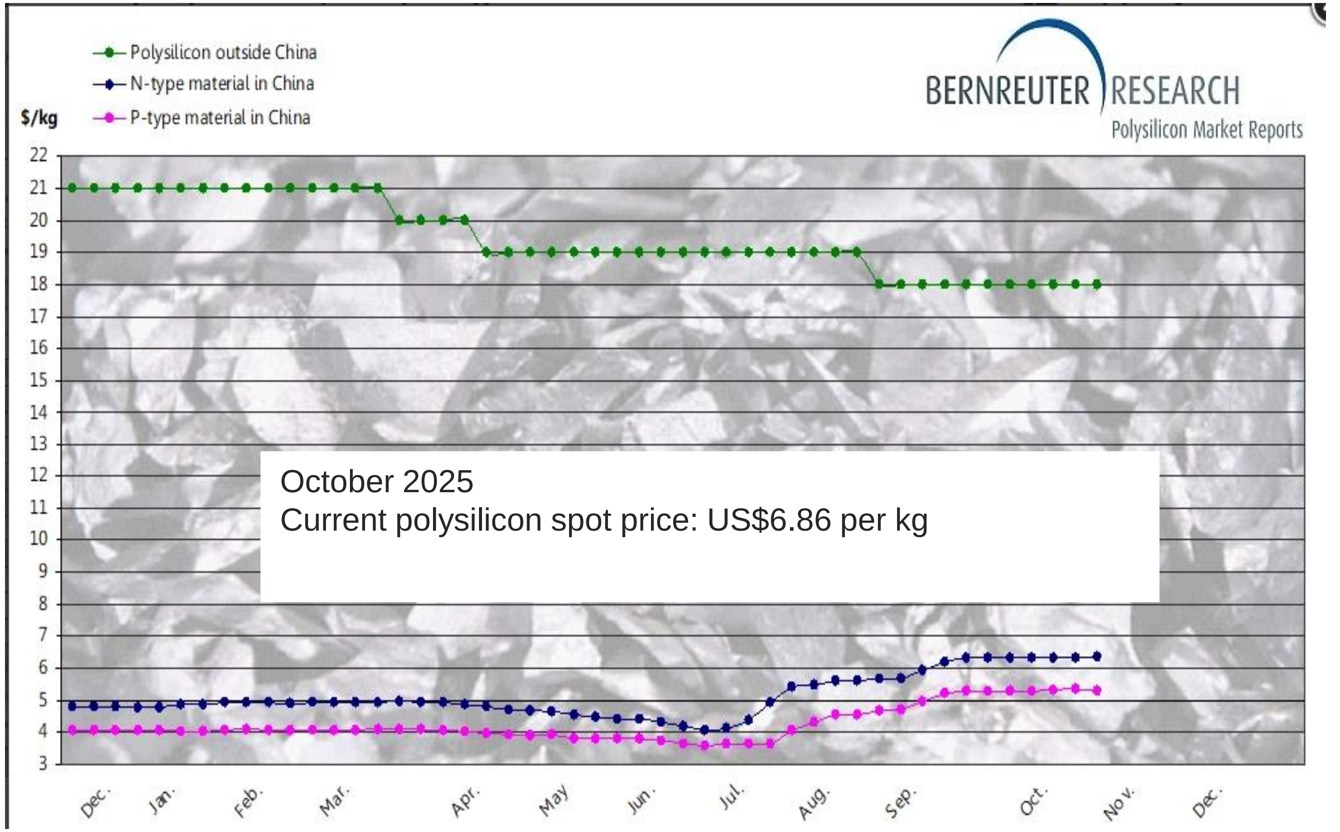
Silicon specification used today in PV industry

- **Solar Grade Silicon (SoG-Si): used in most commercial PV modules**
  - Purity: mostly 9N to12N polysilicon from Siemens or FBR processes
  - Forms: Chunks, rods, granules, chips

- **Upgraded Metallurgical Grade Silicon (UMG-Si): minimum quality requirement for a solar cell**
  - Purity: 6 to 7N, metallurgically refined silicon,
  - Forms: chips, blocks (generally broken from directionally solidified ingots)

Silicon purity scale		
6N	99,9999%	1ppm total impurities
9N	99,9999999%	1ppb total impurities
10N	99,99999999%	0,1ppb total impurities
11N	99,999999999%	0,01ppb total impurities

	Resistivity (Ohm.cm)	Carrier lifetime over resistivity (τ/ρ) µs/Ohm.cm	Interstitial oxygen (O_i) ppma	Substitutional carbon (C_s) ppma
SHJ	0,4 to 1,6	>> 3000	≤ 11	≤ 1



Sustainable silicon production

Re Si lex

Evaluation at the ingot level of the photovoltaic properties of the recycled silicon produced

- To assess the suitability of recycled silicon for solar cells production
- To define the best way to produce ingot

Sustainable silicon production

"Recycled silicon" production

Medium scale slag	Large scale slag @ ELKEM
Silicon purity level reached: 98,91%	Silicon purity level reached: 97,79%

Vacuum refining step

Additional purification steps:

Additional directional solidification	Additional Cz growth process

Recycled silicon ingot after directional solidification

[B]= 11 ppmw
[P]=2,6 ppmw
[Al]=0,4 ppmw

Silicon purity in the range of 2N (99%) to 4N (99,99%)

Recycled silicon ingot from crystal pulling

Silicon purity in the range of 5N (99,999%)

[B]= 1,9 ppmw
[P]=2,5 ppmw
[Al]=0,3 ppmw

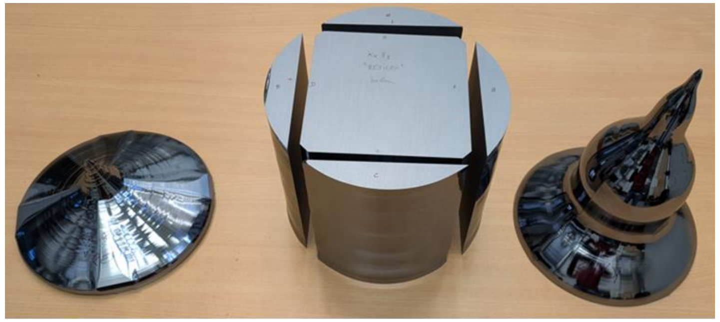
Sustainable silicon production

- Production of recycled silicon was carried out by NTNU:

Recycled silicon ingot after directional solidification

- 1st Cz ingot with Boron and Phosphorus concentration added as if we had used 1,8% of the recycled silicon from directional solidification

Resilex Cz ingot n°1



Resilex: M2 brick squaring

Resilex: Brick wafering

700 mono Cz wafers available

- **Assessment of the wafers of the 1st Cz ingot with specific B and P concentration**

1. Measurement of the wafer electrical quality from 5 positions in the ingot
2. Measurement of the material behavior under light

Assessment of the wafers from the 1st Cz ingot

Resilex Cz ingot n°1

Wafer from RESILEX Cz Ingot n°1 (POS 1 to POS 5)

Cleaning
Etching to 130 µm

Reference (130 µm Cz n-type wafer from Longi)

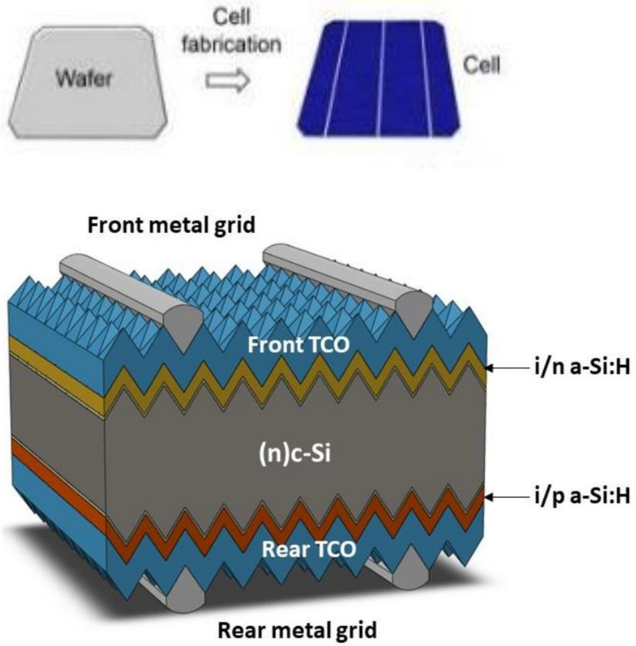
1) WET chemicals

2) PECVD a-Si

3) PVD TCO 100 nm Front & Rear

4) Screen-printing Ag paste

5) Curing



Assessment of the wafers from the 1st Cz ingot

Resilex Cz ingot n°1

1) Electrical quality measurement:

→ carrier lifetime @ 1.10^{15} cm^{-3} injection level

→ Implied V_{oc} (iV_{oc}) @ 1 suns

Wafer from RESILEX Cz Ingot n°1 (POS 1 to POS 5)

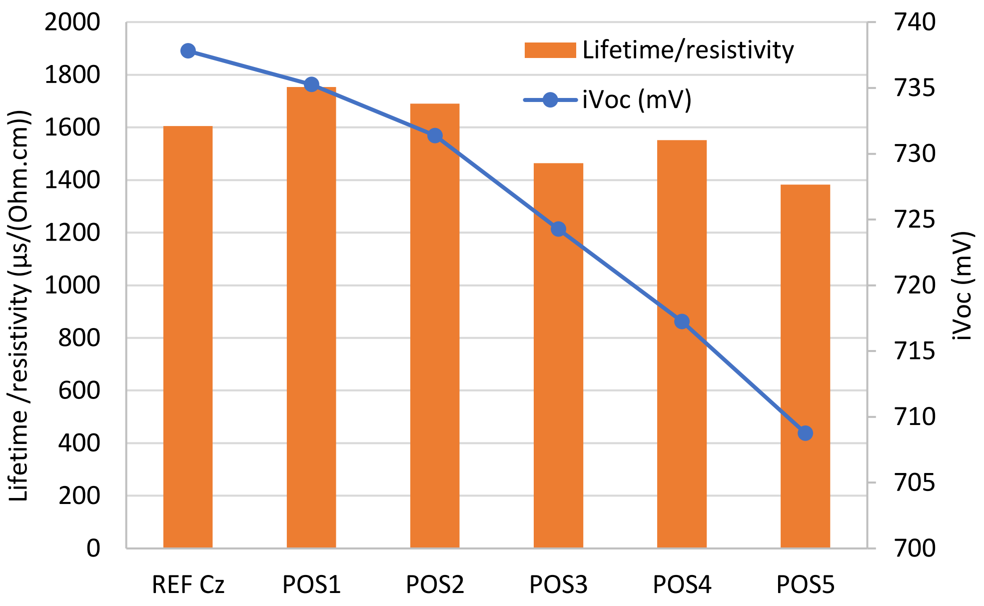
Cleaning Etching to 130 µm

Reference (130 µm Cz n-type wafer from Longi)

1) WET chemicals

2) PECVD a-Si

Averages values on 5-8 wafers



Assessment of the wafers from the 1st Cz ingot

Resilex Cz ingot n°1

2) Lifetime and iVoc variations under light exposure: 60°C & 0.5 suns

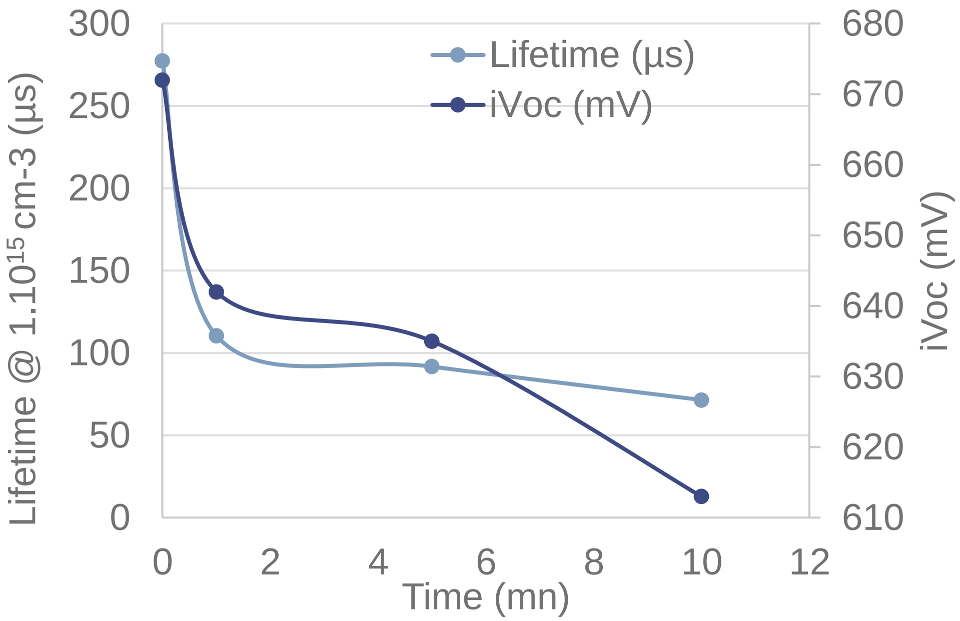
Wafer from RESILEX Cz Ingot n°1 (POS 1 to POS 5)

Cleaning Etching to 130 µm

Reference (130 µm Cz n-type wafer from Longi)

1) WET chemicals

2) PECVD a-Si



- Evolution under light could be explained by the Boron concentration in the wafers

→ Experiment to be continued with regeneration tests to verify that it is B-O defects

Sustainable silicon production

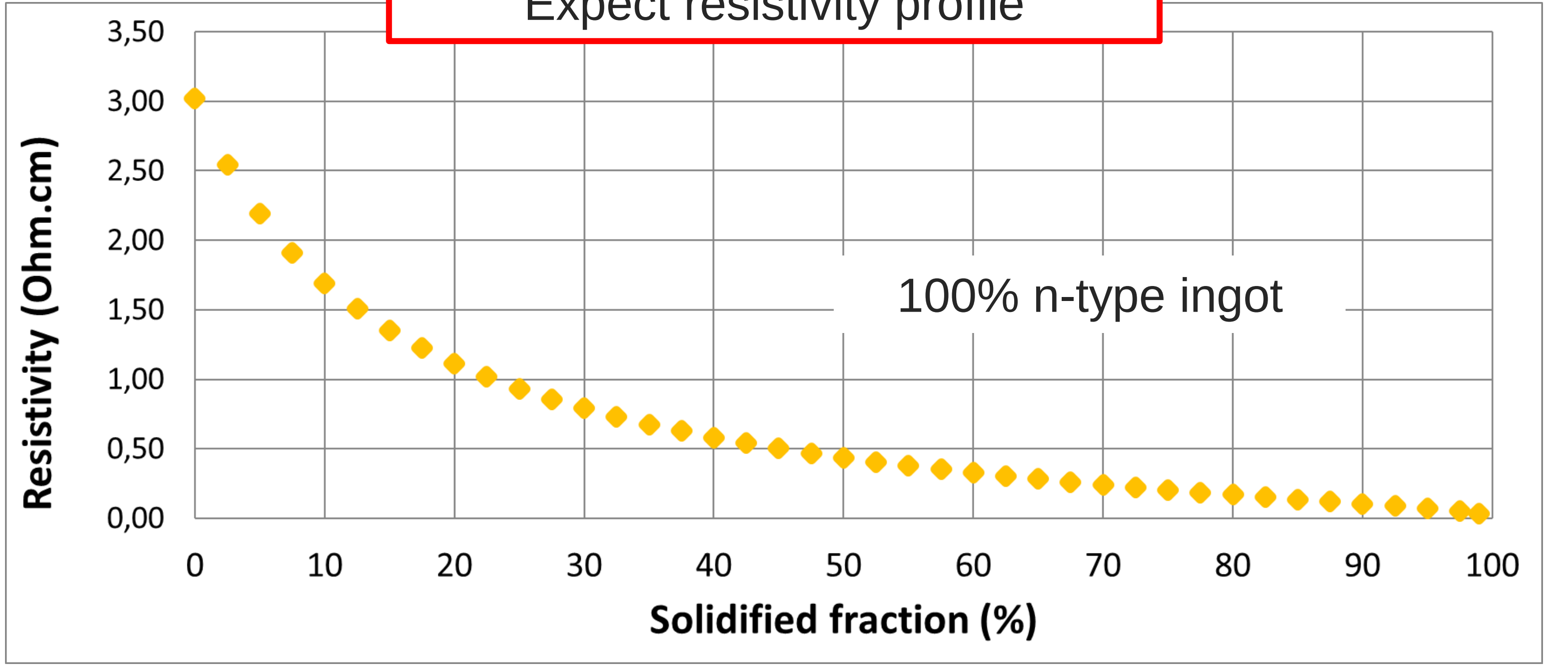
- Production of recycled silicon was carried out by NTNU:

Recycled silicon ingot after Cz growth process

- 2 Cz ingots using respectively ~11% and ~12% recycled silicon feedstocks from Cz growth process

- Additional dopant [P]: 1,3 ppmw ~6,5 time higher than for a Cz ingot without recycled silicon

Expect resistivity profile



Sustainable silicon production

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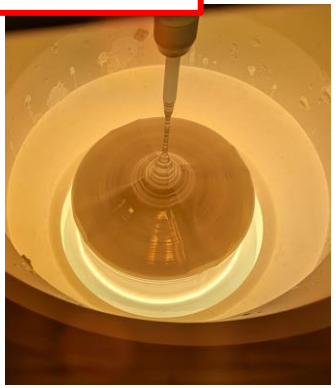
12% recycled silicon feedstock

Recycled silicon: 3,5kg

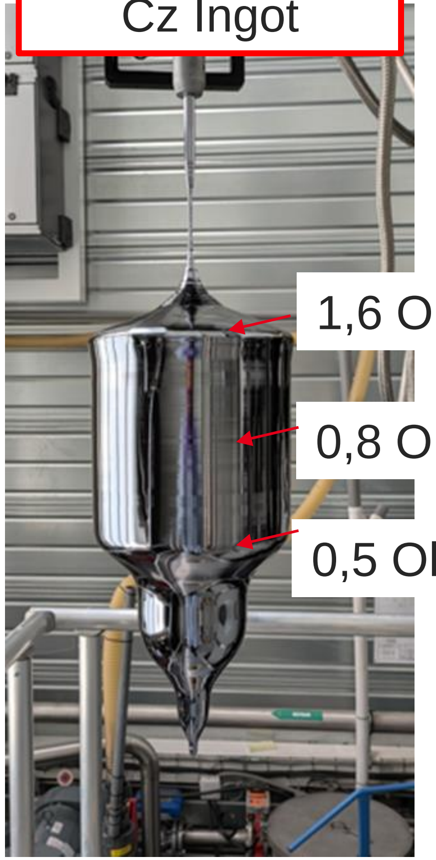


Body step

Loaded crucible: 30kg

Final step: Tail

Monocrystalline Cz Ingot



Resilex Cz ingot n°3

Summary and next steps

- NTNU sent to CEA two “recycled silicon” ingots
- CEA performed impurities analyses on the two “recycled silicon” feedstocks to assess the suitability of the waste material for the production of solar cells
- CEA pulled one 30kg Cz ingots using the results of impurity analysis (GDMS) of silicon feedstocks from directional solidification process
- CEA pulled one 30kg Cz ingots using respectively 12% recycled silicon feedstocks from Cz growth process .
- These ingots meet the resistivity and type objectives compatible with the manufacture of heterojunction solar cells on the CEA pilot line.

Thank you!

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