European Commission

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PV Module Technology

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National Institute for Solar Energy (INES)

1. What is the share of the module in the total cost?
   A) 25%   B) 37%   C) 46%   D) 63%

2. Can we solder on heterojunction cells?
   A) Yes   B) No   C) It's complicated…

3. What are the advantages of ½ cells module
   A) Lower R_S B) Better yield   C) Lower operating temperature   D) Higher throughput

4. With which cells can we make bifacial module?
   A) PERC   B) IBC   C) Al-BSF   D) SHJ   E) PERT and evolution

You have 1' to note your answers…

Outline

1. Overview of modules technology
   i. Motivation
   ii. Status
   iii. Challenges

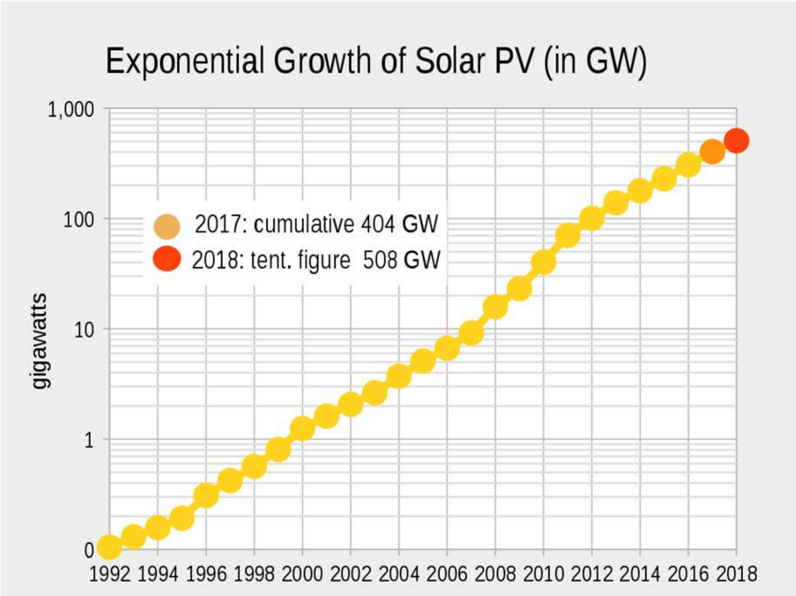
2. Interconnection strategy
   i. Soldering
   ii. SWCT
   iii. ECA

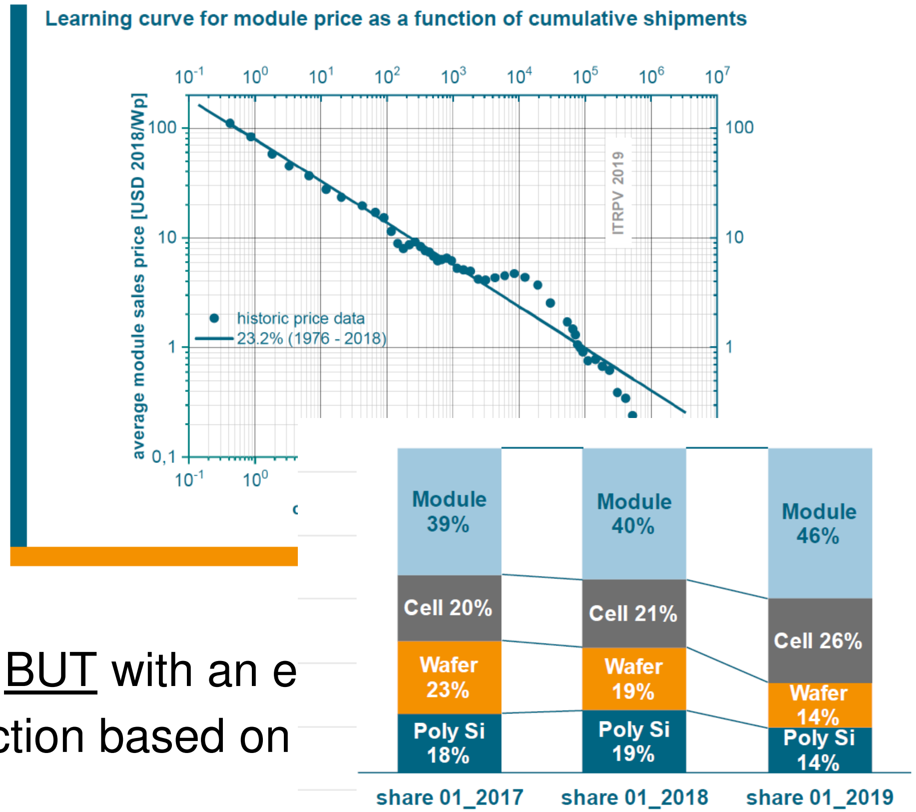
3. Material/Architecture
   i. Encapsulant
   ii. Bifaciliaty
   iii. Full cell? ½ cell? More? Shingle?

4. Perspective

OVERVIEW

Motivation





PV < 1% of world primary energy consumption energy <u>BUT</u> with an e

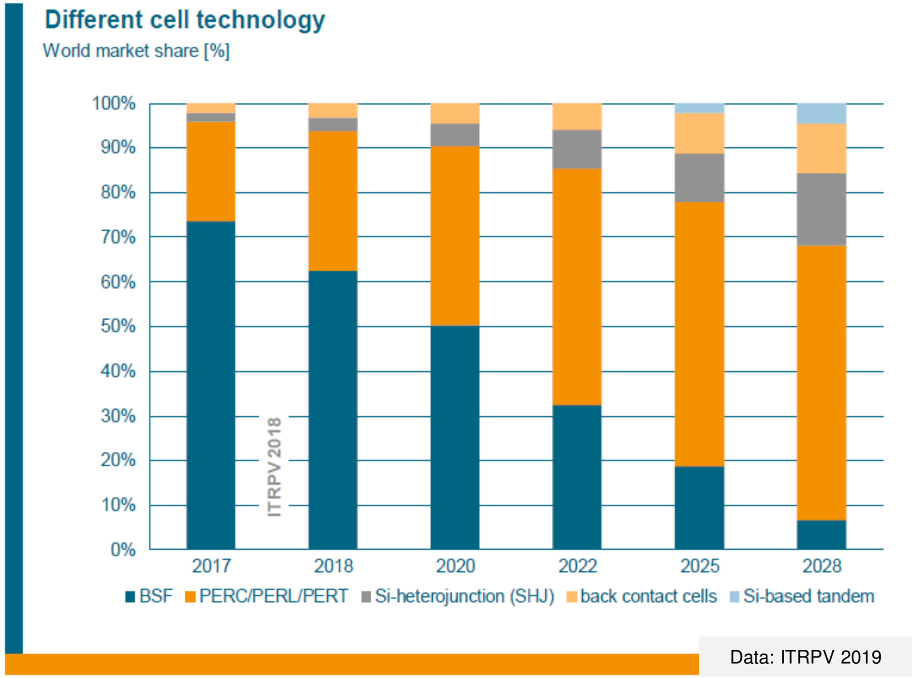
Cost reduction in PV production process → price reduction based on

⇨ Module production costs are about 46% total

Status

Low $/W or $/kWh

Why heterojunction technologies?



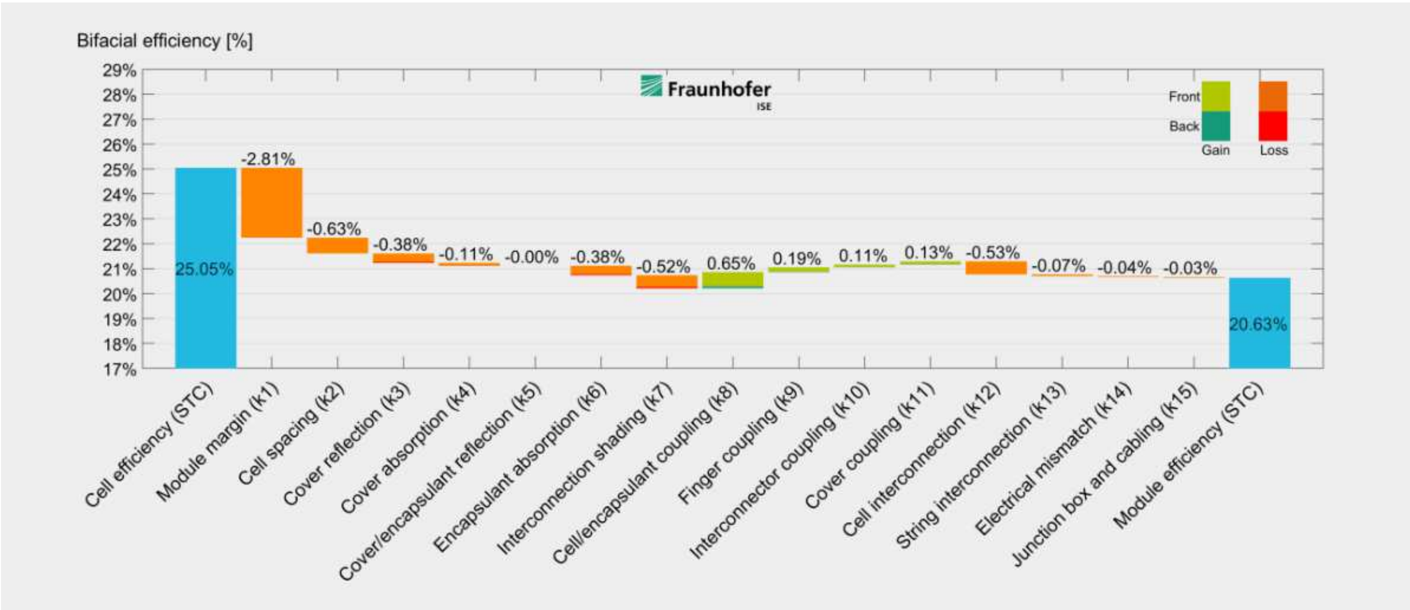
- High conversion efficiency (24.8%)[1]
- Inherently bifacial
- Low temperature coefficient
- Thin wafer capability

[1] http://taiyangnews.info/technology/24-85-efficiency-for-hanergys-hjt-cell/

Motivation

From cell to module = 2 steps

1. Interconnection of cells ⇨ required (I, V) couple
2. Encapsulation ⇨ required performance, reliability/durability



Each step induce power loss/gain

Our goal
=
Maximize gain
Minimize loss
Preserve reliability
Moderate Cost

Challenges

- High efficiency:
  - CTM
  - Surface density
- Reliability:
  - IEC 61215
  - IEC 61730
- Lifetime : >35 years

- Interconnection strategy
  - Soldering
  - SWCT
  - Gluing
  - Shingling
- Material choice
  - Encapsulant
  - Glass / Backsheet
- Architecture

INTERCONNECTION STRATEGIES

Interconnection strategy

SHJ[1]

Standard		Development	
Print + SWCT	Print + ECA-Gluing	Plating + soldering	Print + soldering

It is necessary to think about interconnection from the metallization process!

1. Soldering
   - Screen-printing or plating?
   - Cu-ribbons or Cu-wire coated with low eutectic alloy (Bi, In)

2. Wire interconnection (SWCT, MeyerBurger):
   - Electrode = Cu-**wire** coated with low-melting temperature alloys, supported by a polymer **foil**

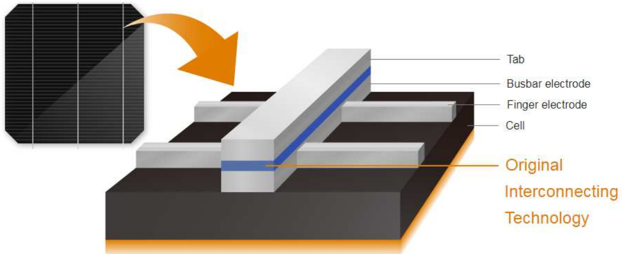
3. Gluing (Electrically Conductive Adhesive = ECA)
   - Ag-particle based, crosslinkable polymer paste

[1]Faes A. *et al.*, Photovoltaics International 41 (2018), 65

Industrial solutions today

Print + soldering

- Panasonic HIT technology



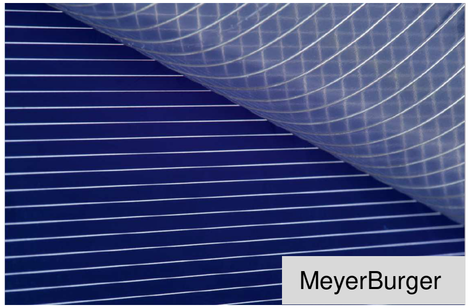
Collaboration with GS Solar

https://panasonic.net/lifesolutions/solar/technology/index.html
https://panasonic.net/lifesolutions/solar/reliability/index.html#regorous

https://www.pv-tech.org/news/panasonic-partners-with-gs-solar-on-heterojunction-production-and-rd

Print + SWCT

- SWCT MeyerBurger – REC



https://www.recgroup.com/en/downloads/image-video-gallery/rec-alpha-series

https://www.meyerburger.com/user_upload/dashboard_news_bundle/376409e022f7d2ae6f6e29318f8055410774c7fd.pdf

Print + ECA-Gluing

- Gluing ECA – EGP / Hevel

https://www.teamtechnik.com/en/new-energy/stringer-tt/new-technologies/

1- Soldering

- Mainstream process for interconnection today: Al-BSF / PERC / PERT / …

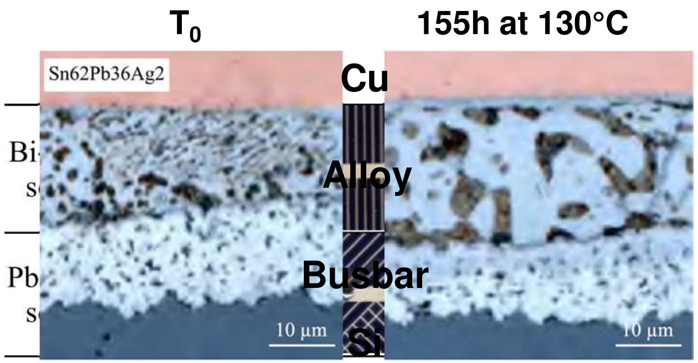
Why soldering step is not widely used with SHJ cells?

- SHJ solar cells are sensitive to temperature.

What are the consequences?

- Process **induce** ITO degradation & passivation damages
- Low temperature silver paste **required!**

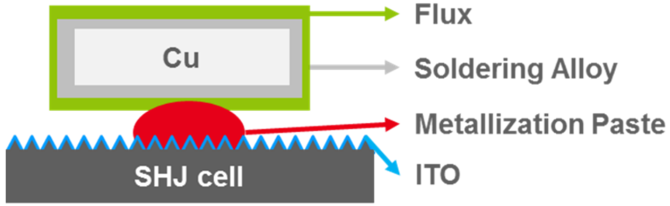
= Wettability / Intermetallic formation challenges



Geipel T. *et al.*, Sol. Energy Mater. Sol. Cells 159 (2017) 370
De Rose A. *et al.*, 33rd EU PVSEC 2017, 710

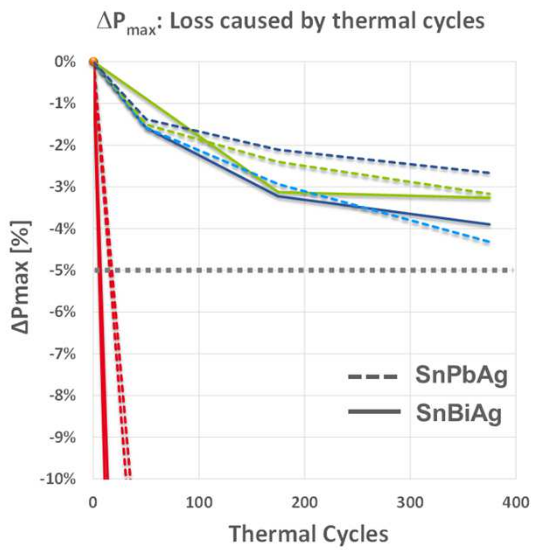
Low temperature screen-printing paste

Ag-pastes, with binders (solvent-polymer combinations)[1]



- Electrical challenges:
  - Conductivity ensured via percolation rather than sintering
  - Layer resistance controlled by Ag content
- Chemical challenges:
  - Wettability
  - Flux / ITO compatibility

  } Reliability challenge (revealed by TC test)



- Economical challenges:
  - Silver paste consumption > 300mg/cell[2]

[1]Commault B. *et. al.*, EUPVSEC (2019)
[2]Faes A. *et al.*, Photovoltaics International 41 (2018), 65

2- Cu Electroplating & Soldering

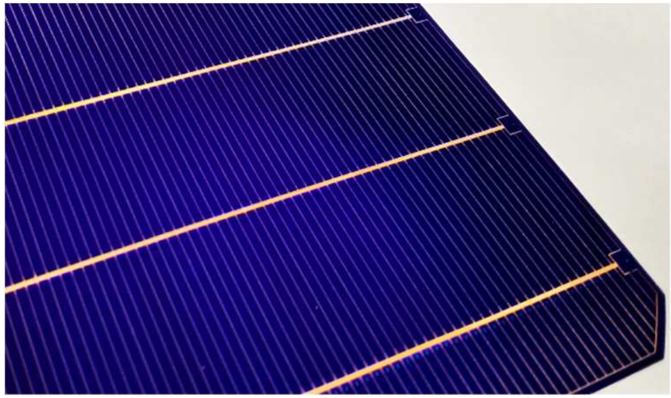
- Replacing Ag screen printing by Cu electroplating:
  - Reduce line resistance
  - decrease overall series resistance of the solar cell by 0.3 Ω.cm²

  } +0,4 → +1% absolute cell efficiency

- 30-µm-wide fingers can be spaced closer:
  - the cell can tolerate higher sheet resistance of the TCO/SiOx stack
  - so TCO/SiOx double layer anti-reflection coating can be used

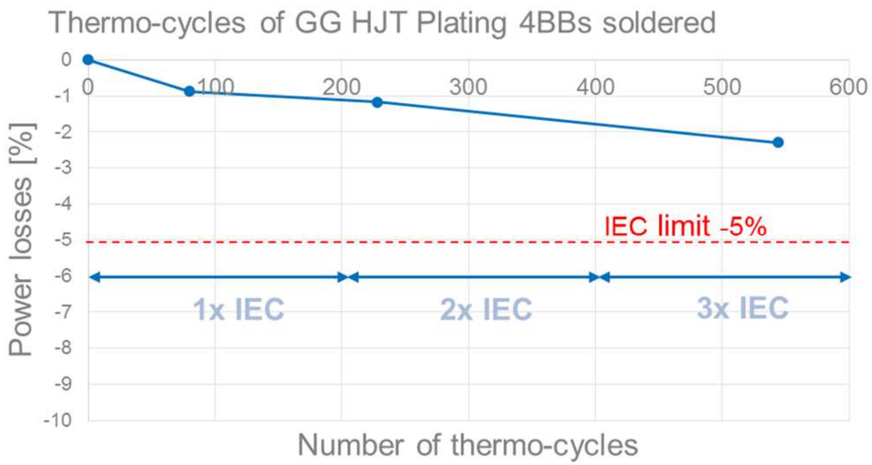
  } +1,5mA/cm² → 1,5% absolute cell efficiency

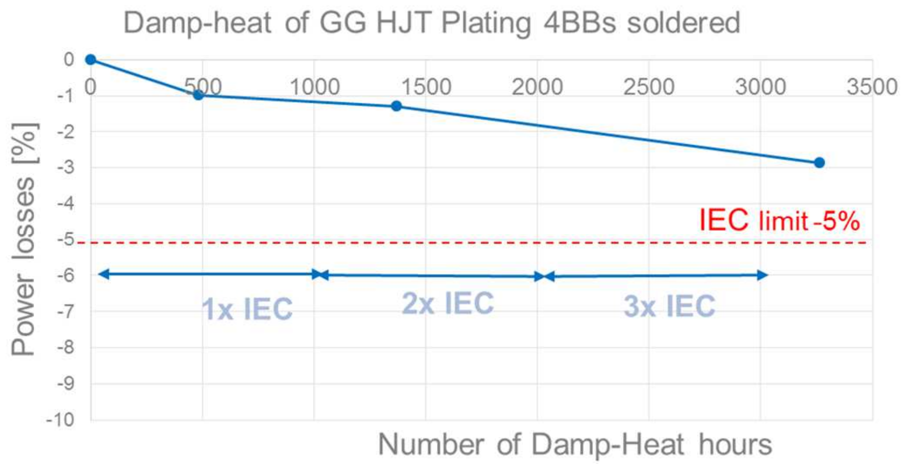
- SWCT or BB soldering possibilities



Cu Electroplating & Soldering

- Excellent module stability demonstrated after 3x IEC norm[1]

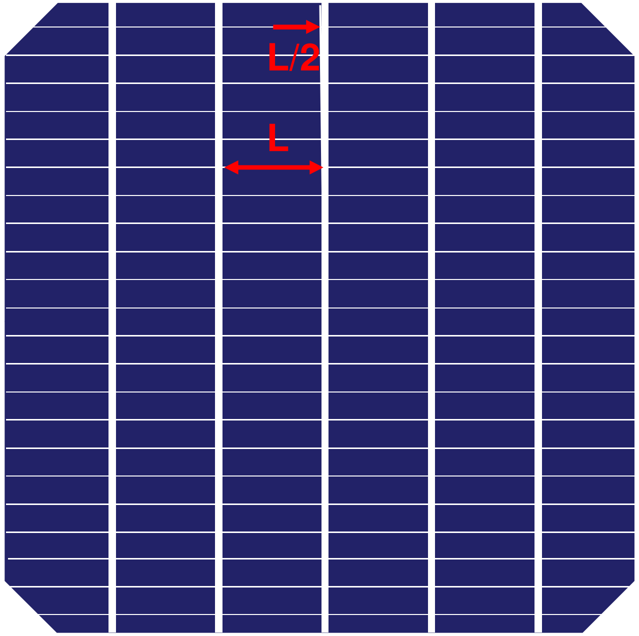




[1]Lachowicz. *et al.*, EUPVSEC (2019)

3- SWCT

- Why choosing SWCT?
  - Less silver paste consumption (80% less silver) / less resistive loss



Electron are transported through ribbons or wire from one cell to another

In the cell, electrons are transported in the fingers

➔ In the cell : D_{MAX} = L/2 and $I_{MAX,BB} = I_{MAX}$ / BB number

Configuration	D_{MAX}	$I_{MAX, BB}$
BB4	18,5mm	2,25A
BB5	15,5mm	1,8A
BB6	13mm	1,5A

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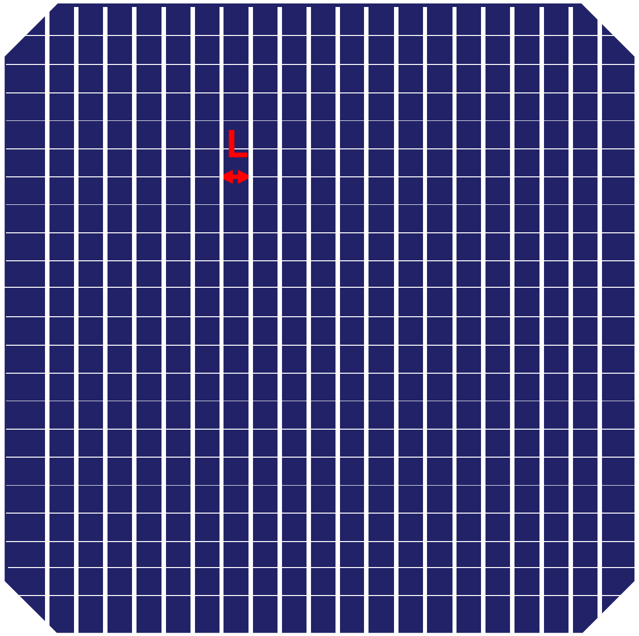

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In the cell, electrons are transported in the fingers

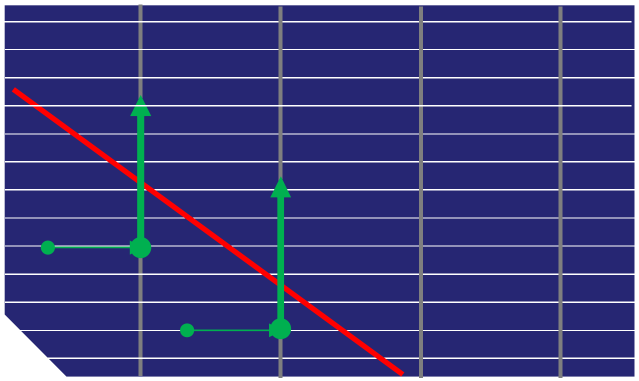
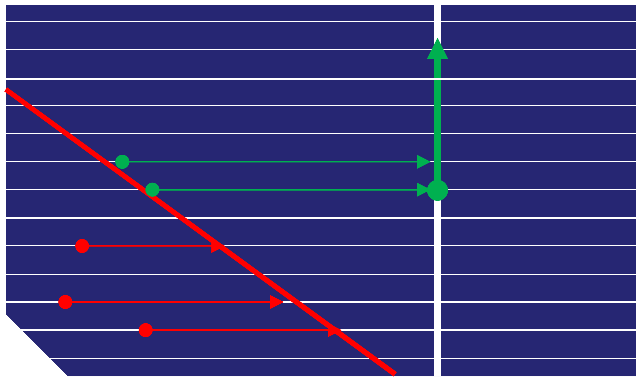
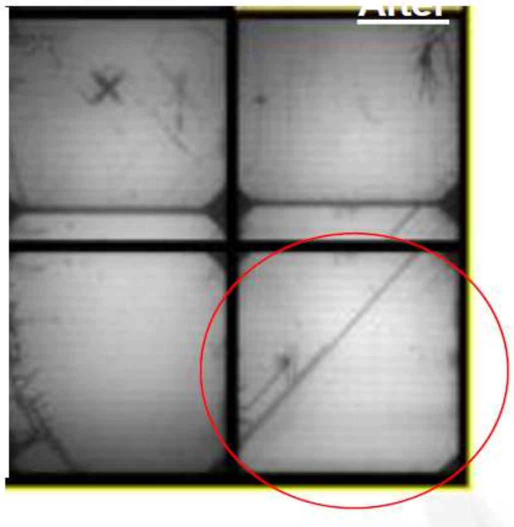
➔ In the cell : D_{MAX} = L/2 and $I_{MAX,wire}$ = I_{MAX} / BB number

Configuration	D_{MAX}	$I_{MAX, wire}$
BB0 – 18 wires	4mm	0,5A

- No BusBar!
- Thinner fingers!

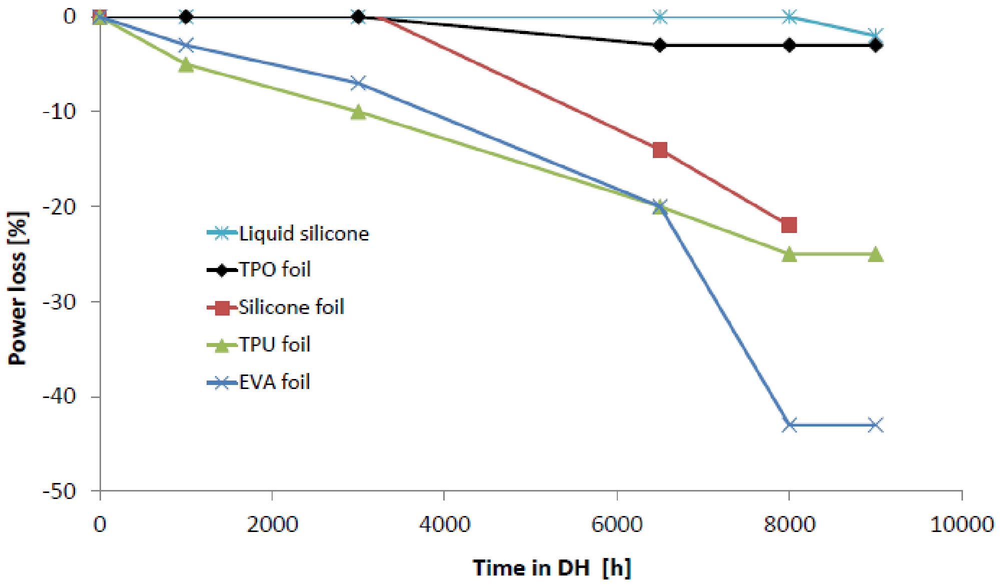
3- SWCT

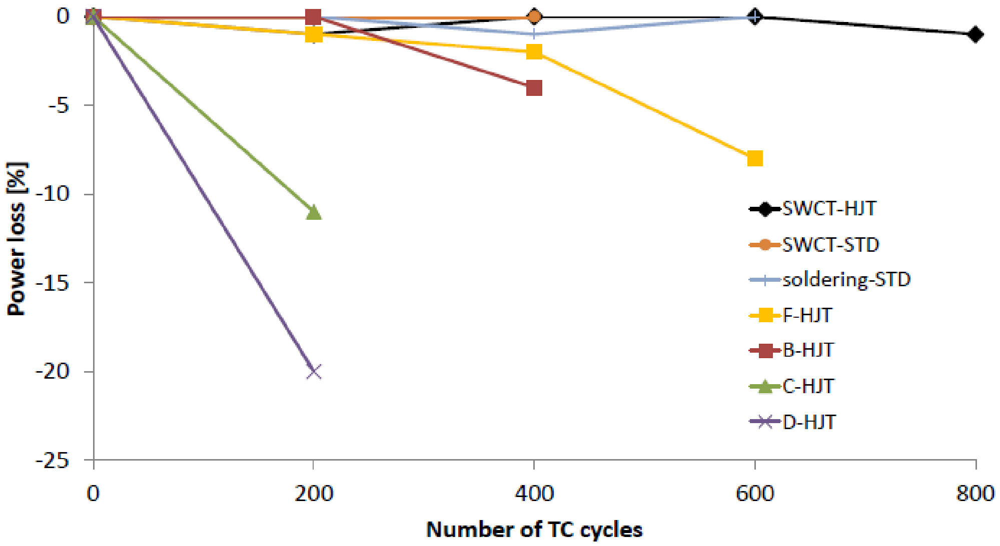
- Why choose SWCT?
  - Less sensitive to cracks!

SWCT

- Why choose SWCT?
  - A reliable solution





4- ECA

- Ribbons interconnection attached with electrical conductive adhesive

How to deposit the ECA?

- Screen Printing
- Valve Jetting
- Dispense

Curing

TT

EFD

4- ECA

- Polymeric adhesives filled with metallic particles
  - Epoxies, acrylates, silicones and hybrids
  - Ag, Ag-coated Cu particles - graphene, carbone nanotube

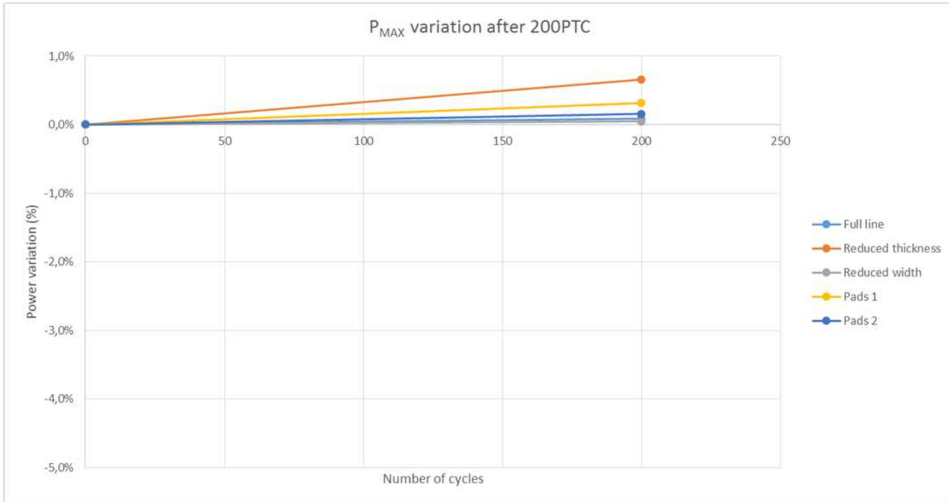
- Use of lead free ribbons – possible texturation (1-2% I_{SC} gain)

- Lower Mechanical stresses

- Low process temperature (120-180°C)
  - Shrinkage and removal of lubricants during cure

4- ECA

- Certification of a SHJ BOM at EGP beginning of September (ECA)
- **Next move**: reduction of ECA quantity (~500-1000€/kg)
- Different possible strategies :
  - Reduction of width of ECA
  - Reduction of thickness of ECA
  - Pads rather than full lines



MODULE FABRICATION

Materials

Encapsulant

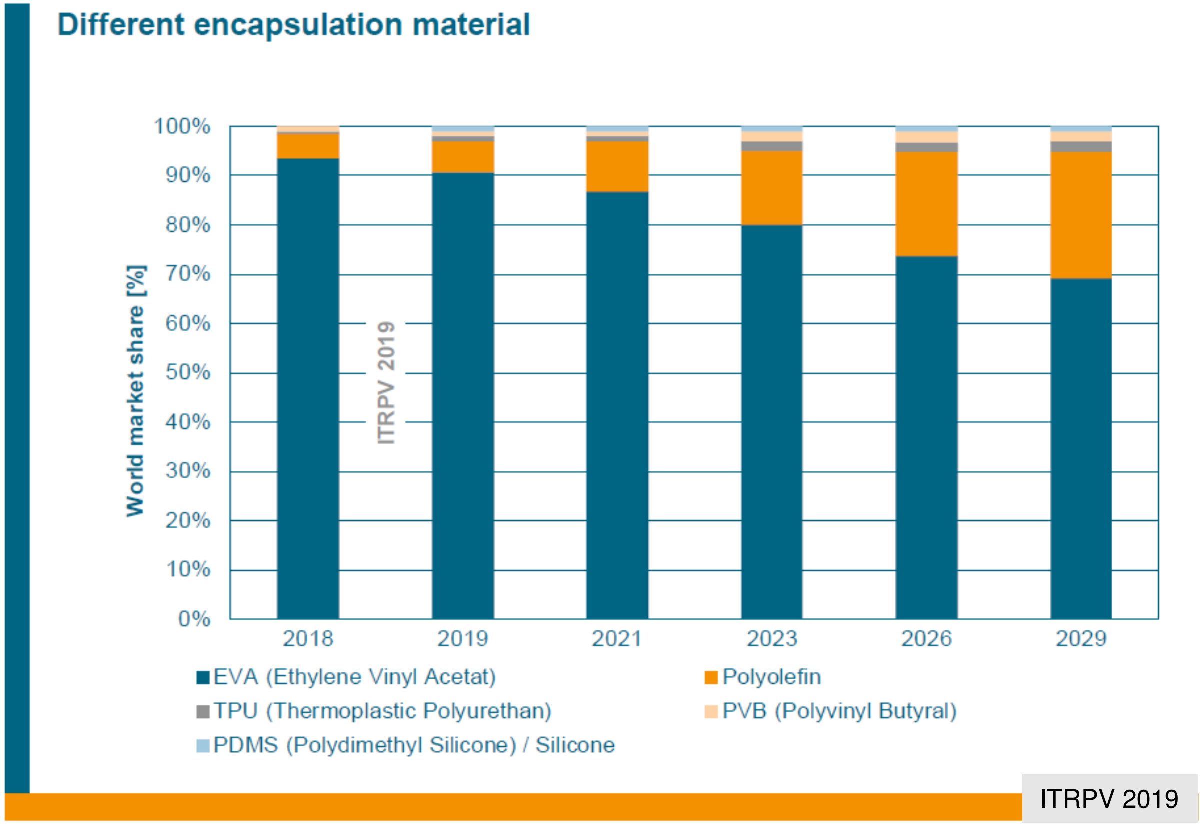


Fig. 15a: Expected market shares for different encapsulation materials.

- EVA > 90% of the market (today)
  - Degradation product = acetic acid
  - SHJ sensitivity
  - EVA from Ampere project show the worst results
- POE
  - Less degradation product over time
- TPO
  - No cross-linking reaction during lamination = possibilty to reduce time = higher throughput

Glass/Backsheet

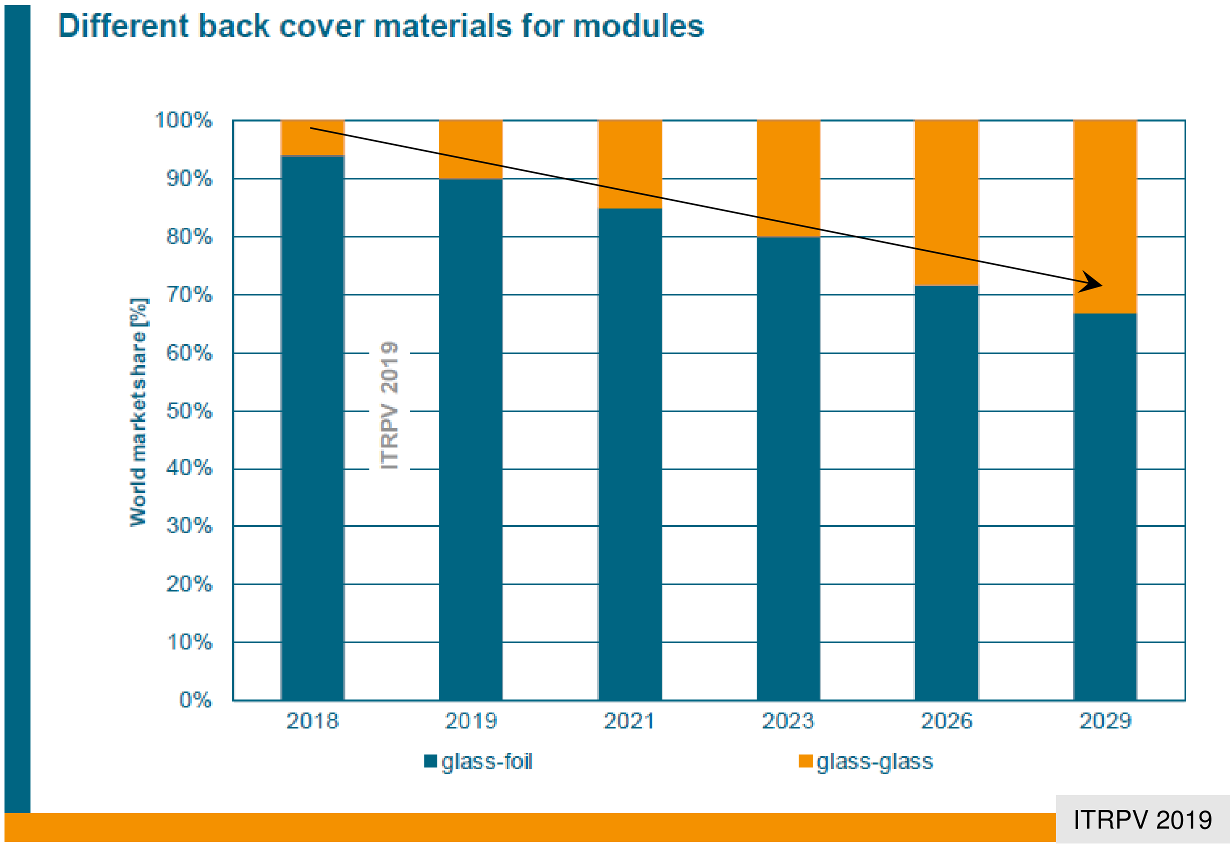
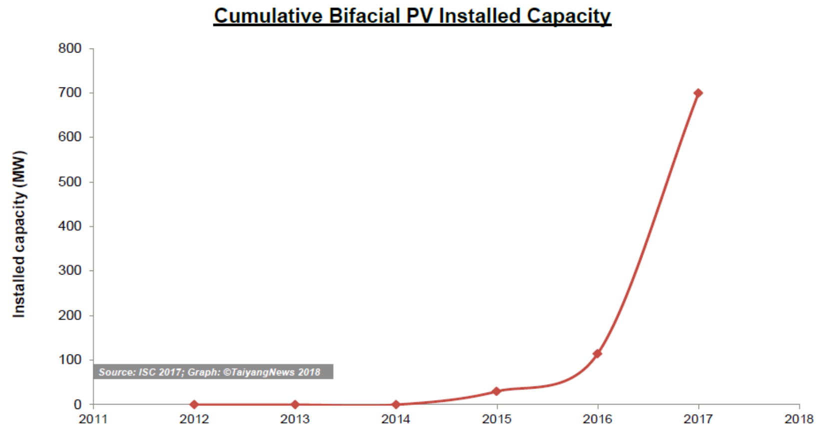
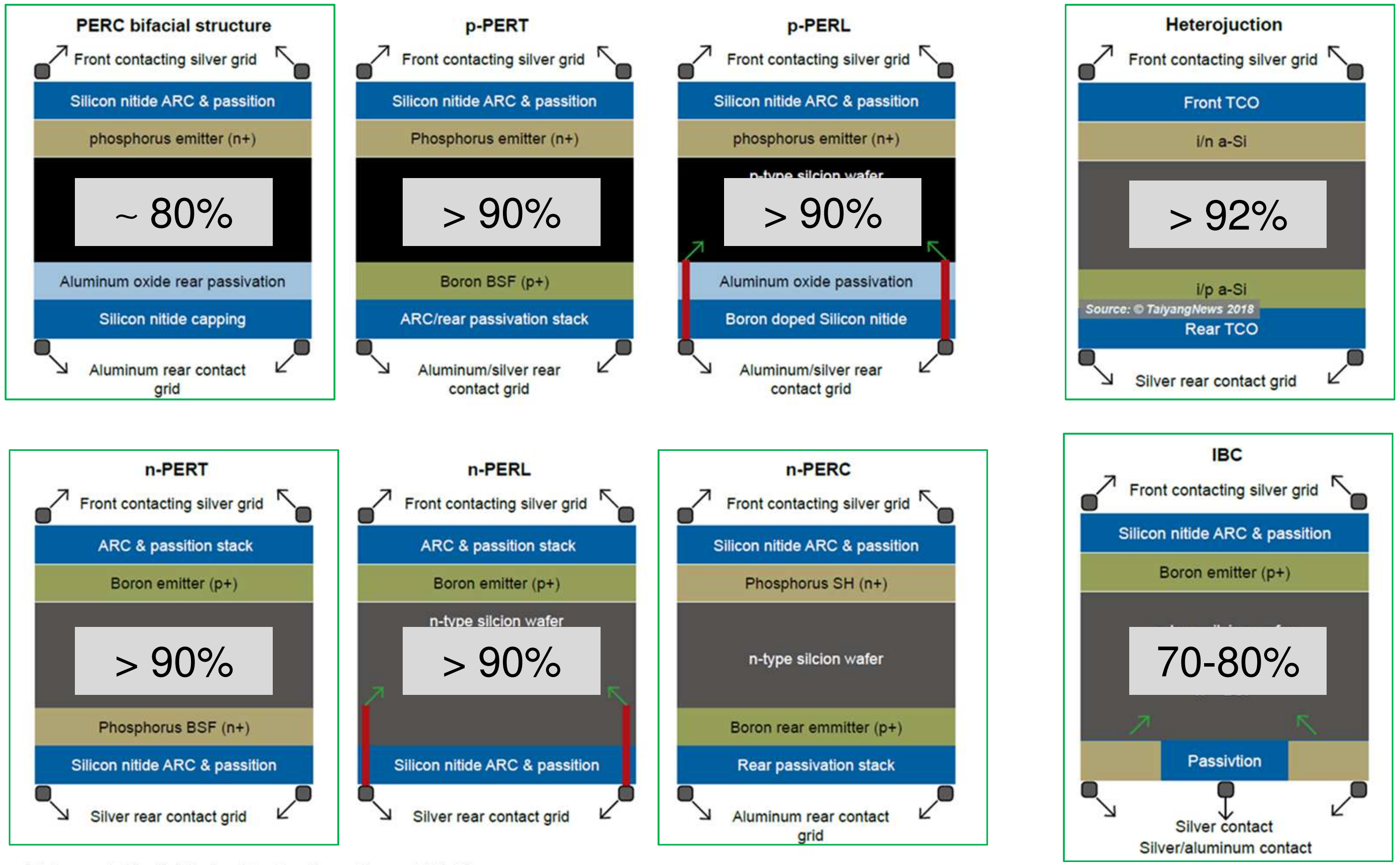


Fig. 16a: Share of glass-foil and glass-glass as back cover technologies.



- Exponential increase of bifacial PV
- Mainly Glass/glass module

Bifaciality



Taiyang Bifacial Solar Technology Report 2018

Bifacial Photovoltaics. Technology, applications and economics *Joris Libal and Radovan Kopecek*

Glass/Backsheet

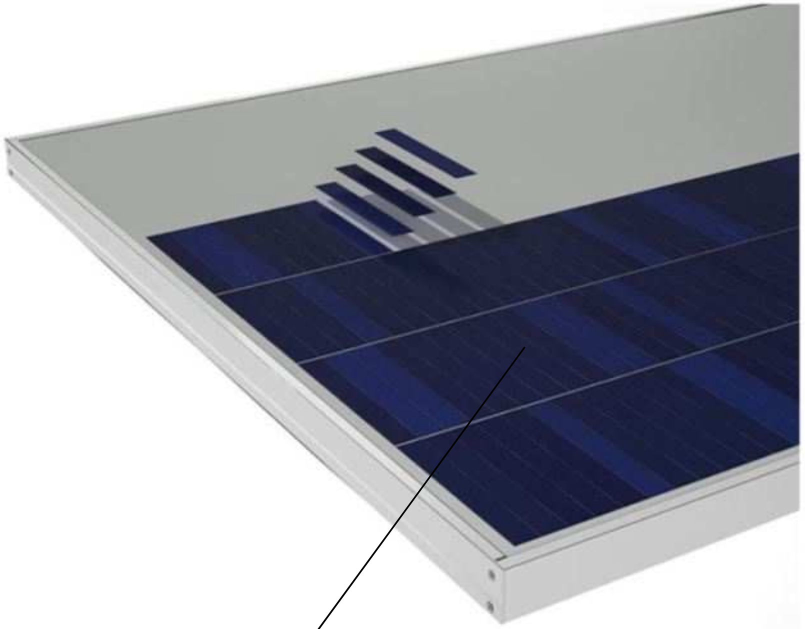
- Different strategies:

Glass/Glass	Glass/Transparent backsheet	Glass/White backsheet
✅ Better water barrier/ UV resistance → lifetime expectancy =35y ✅ Better electric insulation ✅ Better cell mechanical resistance = neutral fiber ✅ No frame ✅ Bifaciality! ❌ Heavy (>30kg for 72c module) ❌ Inferior module mechanical resistance	✅ Standard module manufacturing ✅ Better breathability (acetic acid permeation) ✅ Weight ✅ Bifaciality ❌ DH/UV resistance	✅ Standard module manufacturing ✅ Better breathability (acetic acid permeation) ✅ Weight ✅ Reflection backside ❌ DH/UV resistance

JinkoSolar/Dupont

Architecture

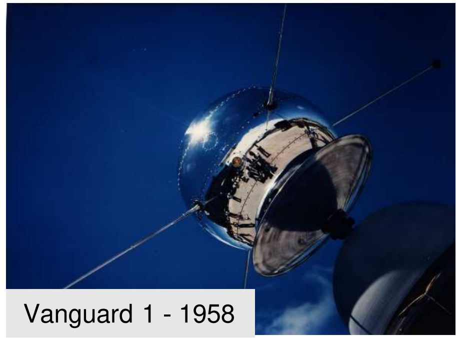
Shingle



Full area utilization

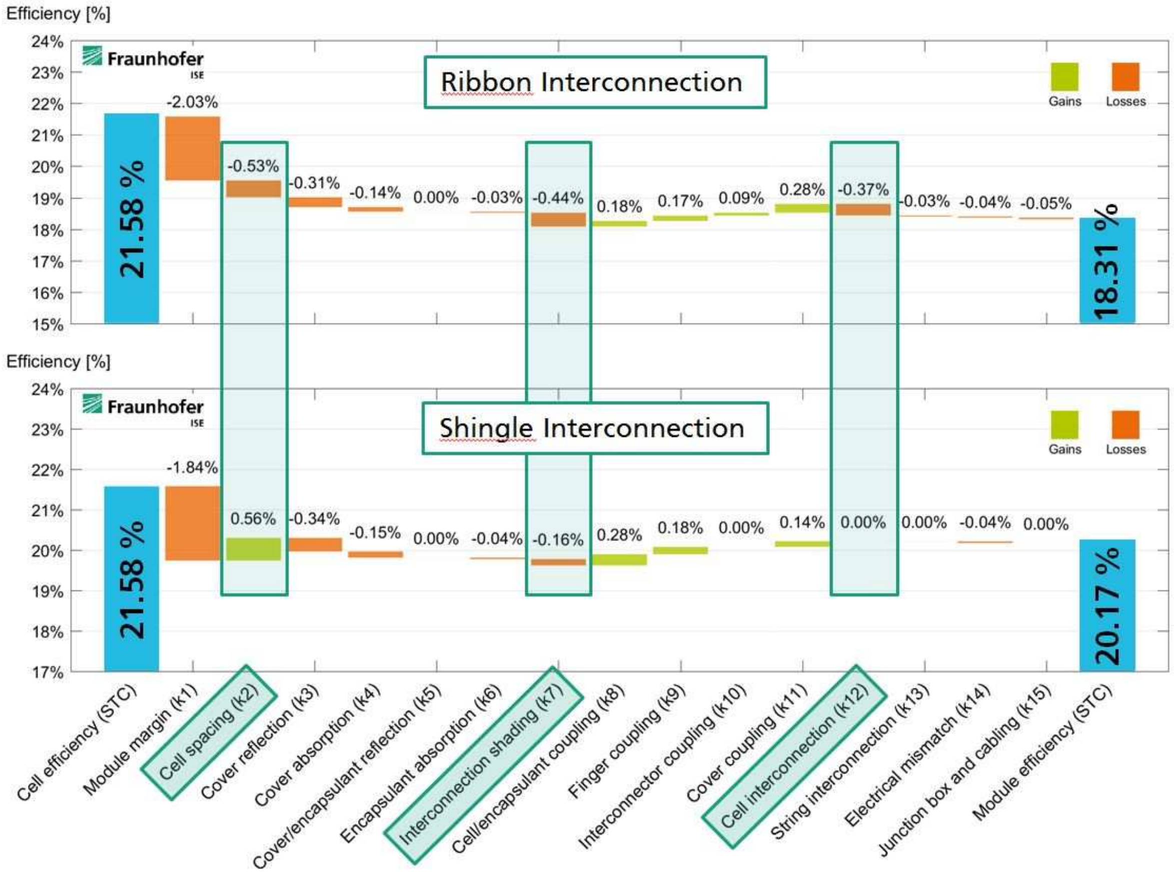
"Novel" cell interconnection technology

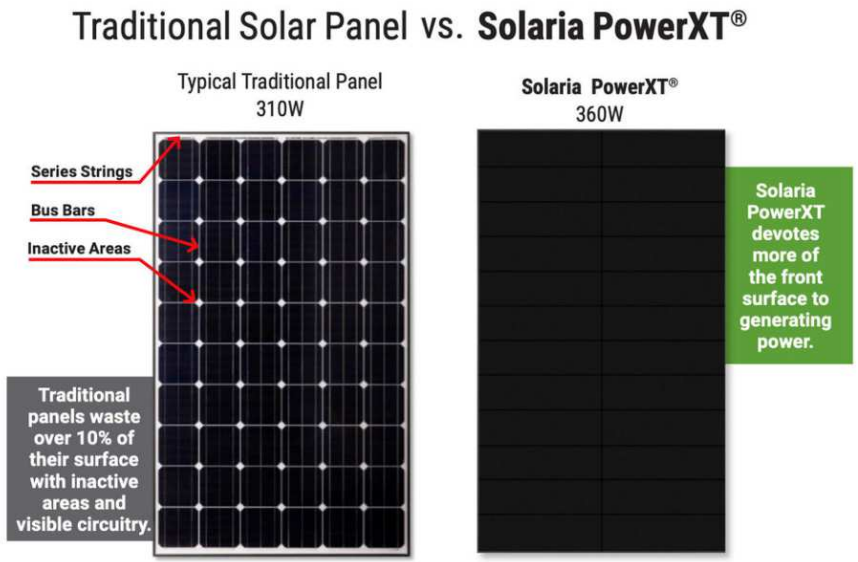
1. Cutting of the cell (1/6)
2. Connected by low temperature curing ECA



- Compatible with any kind of solar cells?
- Minor modifications of module assembly line

Shingle





17.2% ⇨ 20,5%

ARCHITECTURE

Strategy?
Full cell?
½ cells? Shingle?

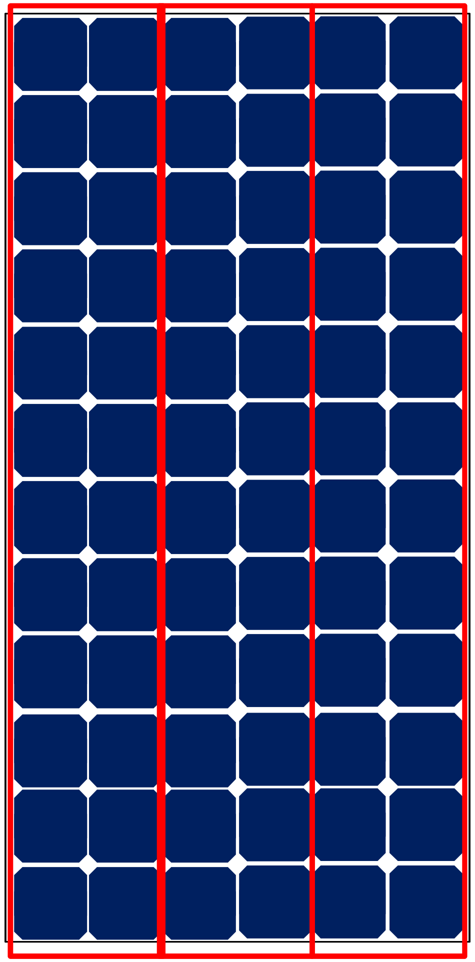
Depends of module location!

- ✅ Less current = less serial resistance losses
- ✅ Less current = less heat = higher performance on field

- ❌ One more step
- ❌ Cell degradation = recombination at the edge

⇨ What choice would you make?

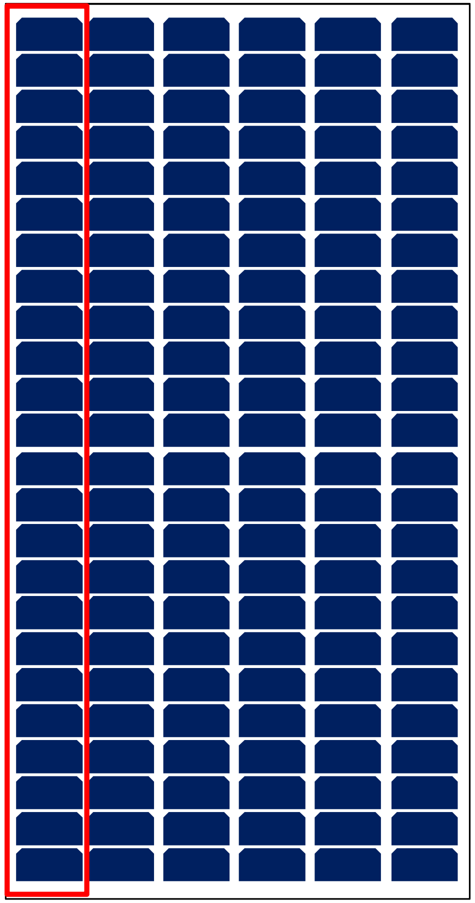
ARCHITECTURE



- **<u>Standard 72 cells module:</u>**
  - About 2m²
  - About 30kg in GG configuration (with 3mm glass)
  - 400W (with cells η = 23%)
  - V_{OC} ~ 50V and I_{SC} ~ 9A (for SHJ solar cells module)
  - 3 Junction boxes (edge to avoid shading)
  - All cells are connected in series.

How integrate ½ cells?

ARCHITECTURE

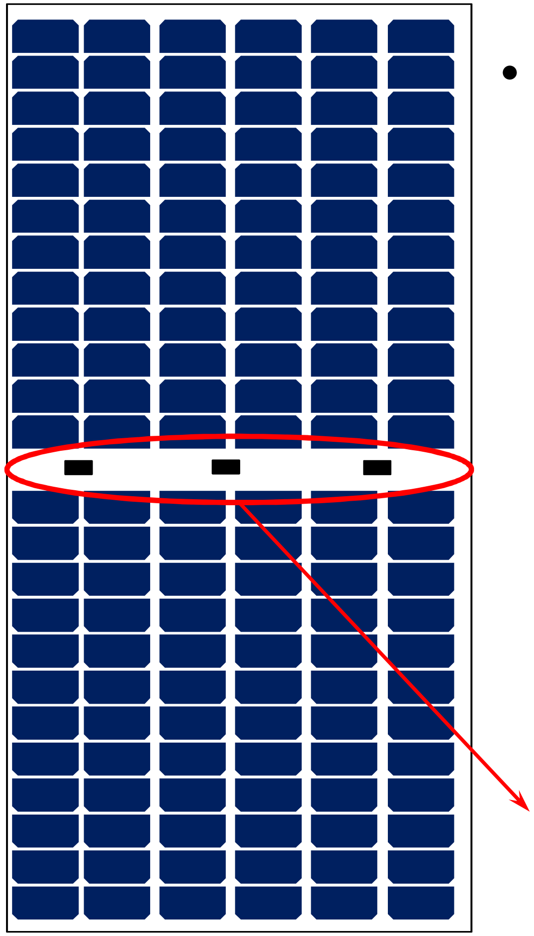


- **<u>144 ½ cells module (all in series):</u>**
  - About 2m² (longer because more intercell space)
  - About 30kg in GG configuration (with 3mm glass)
  - 2% gain
  - V_{OC} ~ 100V and I_{SC} ~ 4,5A (for SHJ solar cells module)

= less module in a string for a 1000V (or 1500V) systems = less power per strings

= need one JB per strings

ARCHITECTURE



- = **Standard 144 ½ cells module:**
  - About 2m²
  - About 30kg in GG configuration (with 3mm glass)
  - 2% gain
  - V_{OC} ~ 50V and I_{SC} ~ 9A (for SHJ solar cells module)
  - Two 'systems' of 72 cells in parallel
  - 3 Junction boxes (edge to avoid shading)
    - ⇨ Hole in the glass

Loss of space

PERSPECTIVE

POWER

- Always more power! How to go to $\eta > 30$ %

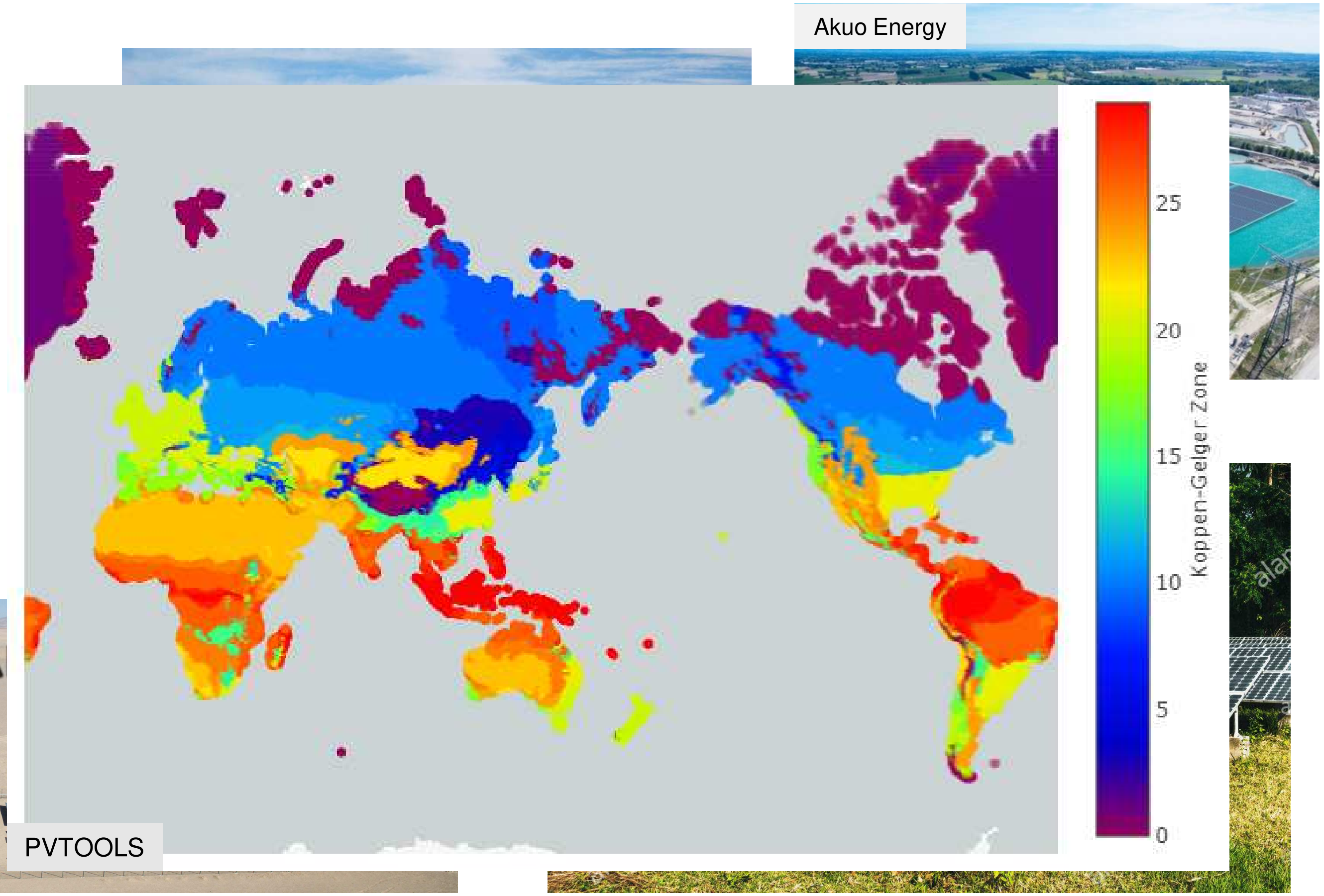
  ⇨ Tandem cell perovskite/silicon, 2T/4T?

  Interconnection issues = no more soldering! T(perovskite) < 120°C

  Encapsulation issues = how to protect perovskite

RELIABILITY

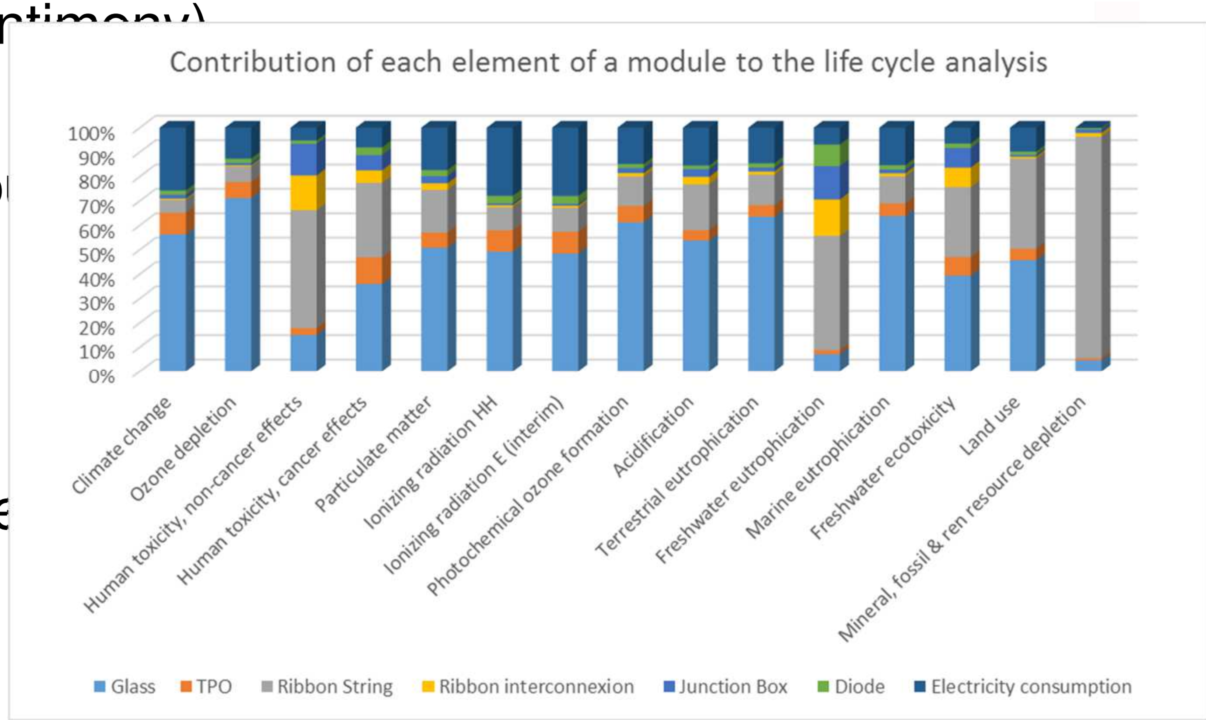
- Reliable in every kind of environment !
- Adapt the module
- Modules tracking → understand early failure



https://pvtools.lbl.gov/pv-climate-stressors

ECO CONCEPTION

- Think of PV production as a circle not a line!
- No more toxic material (lead, an
- Avoid material with limited reso
- Think of CO_2 cost
- Think of the whole impact proce



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   A) 25% B) 37% **C) 46%** D) 63%

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   A) Yes B) No **C) It's complicated…**

3. What are the advantages of ½ cells module
   A) Lower R_S B) Better yield **C) Lower operating temperature** D) Higher throughput

4. With which cells can we make bifacial module?
   A) PERC **B) IBC** C) Al-BSF **D) SHJ** **E) PERT and evolution**

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