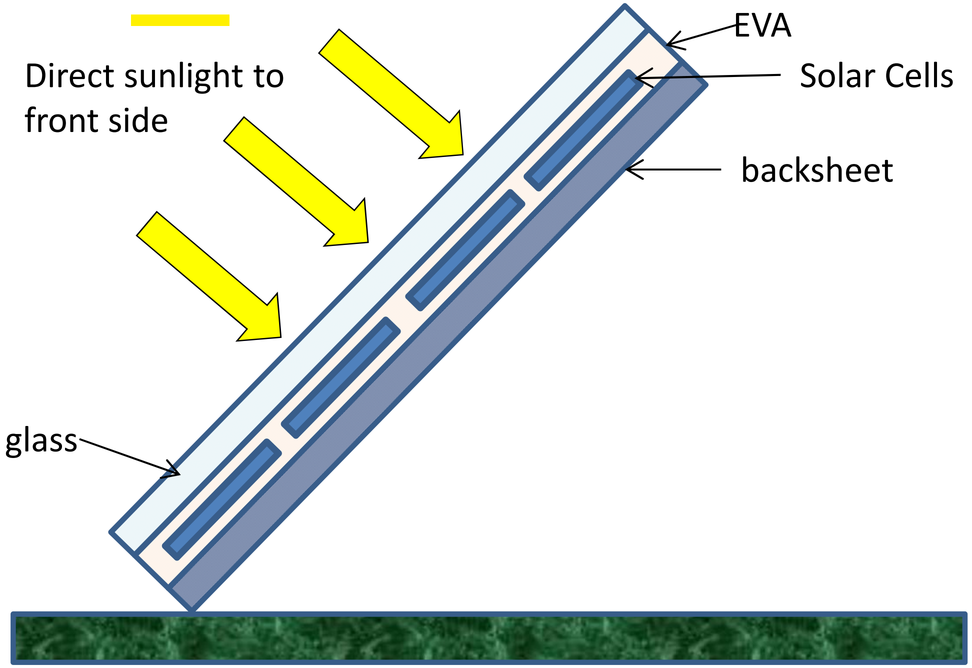
Bifacial PV – now and in the future

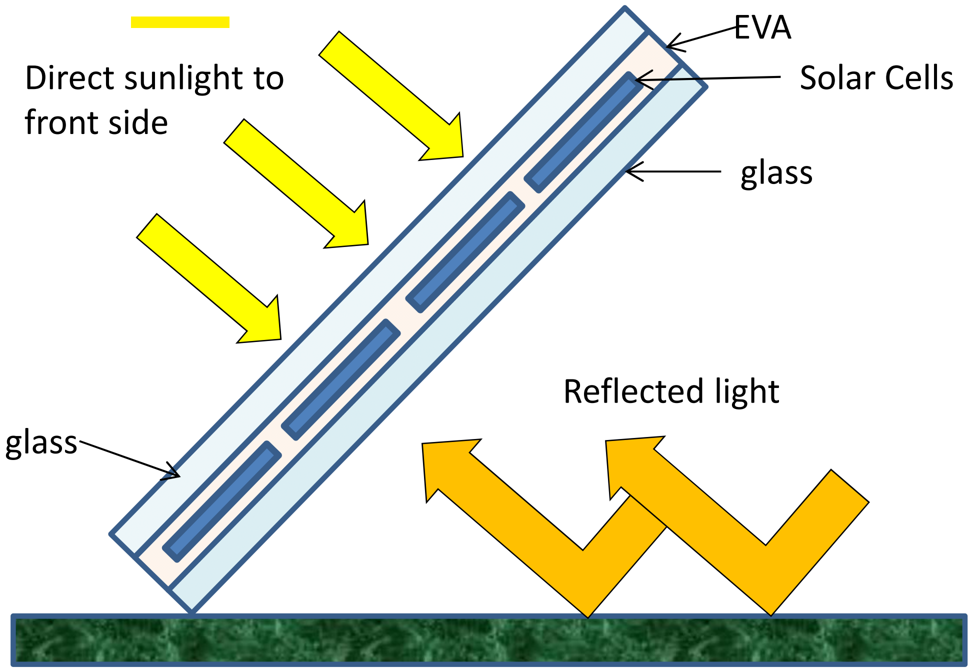
Ingrid Romijn

ECN

Standard module:

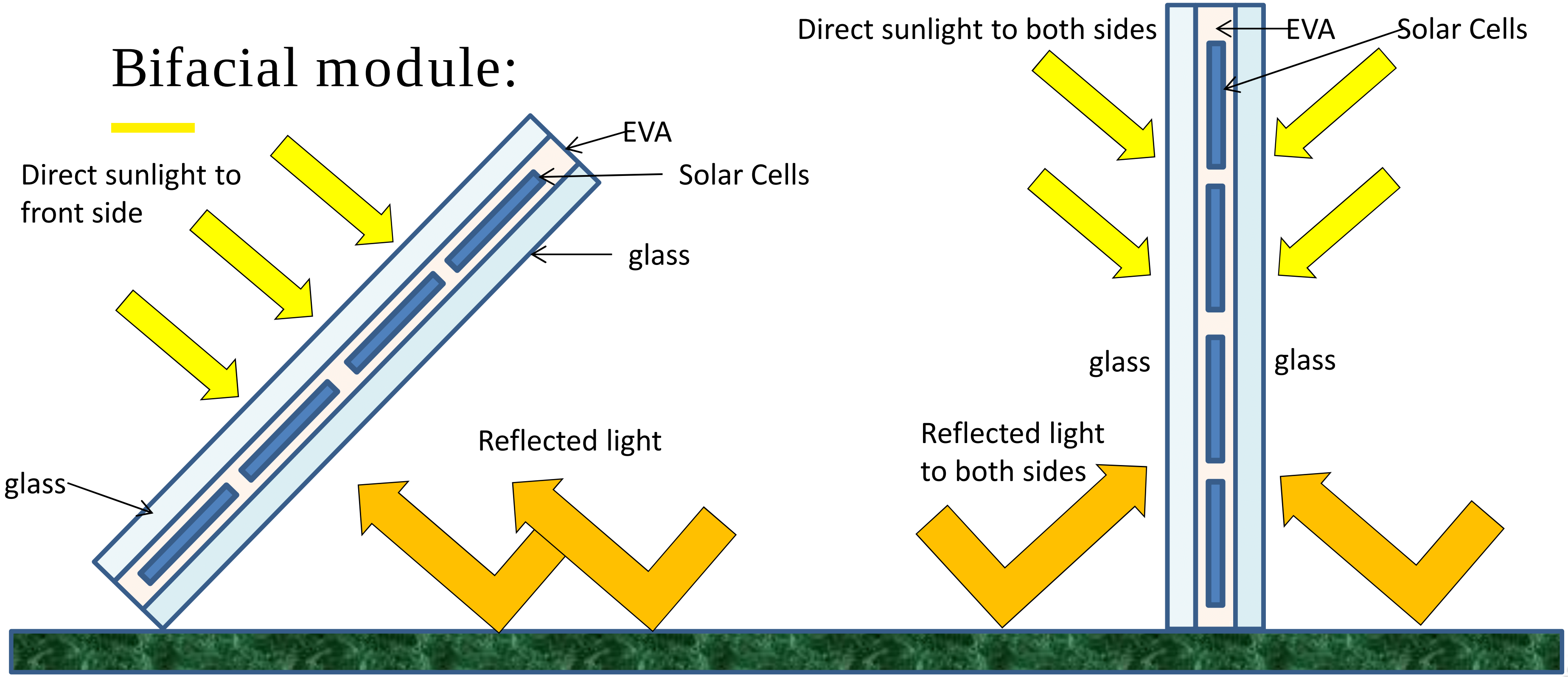


Bifacial module:



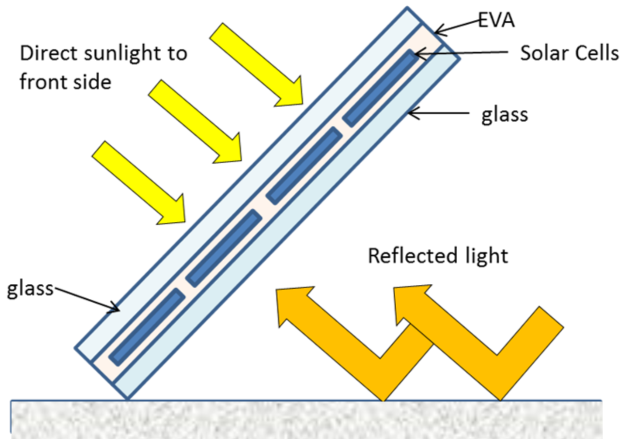
→ Replace opaque rear with transparent backsheet or glass

Bifacial module:



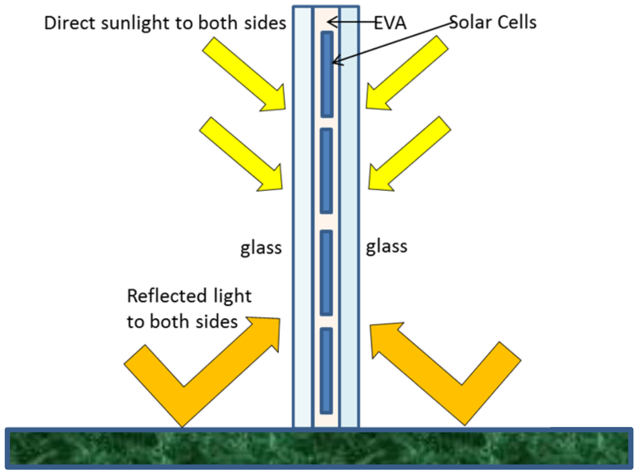
→ Vertical installation possible

Bifacial module:



Installation with high reflection:

- More albedo → higher yield
- +10…… + >30% [kWh/kWp]
- Solar farms, white rooftop, …



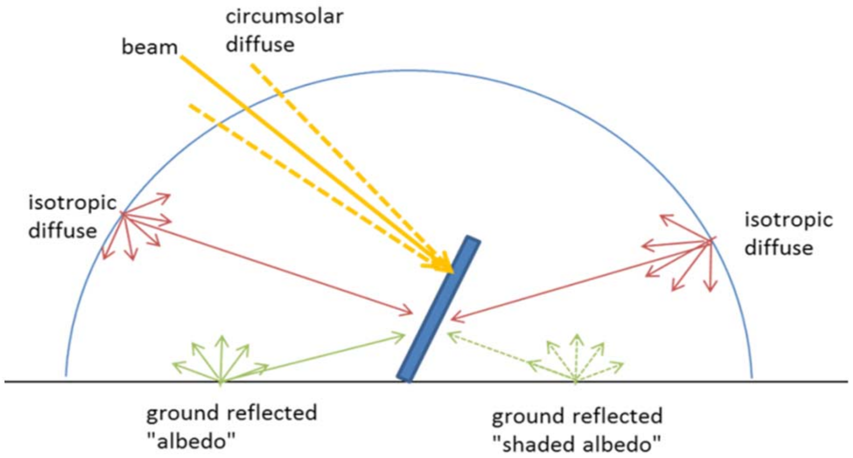
Vertical installation:

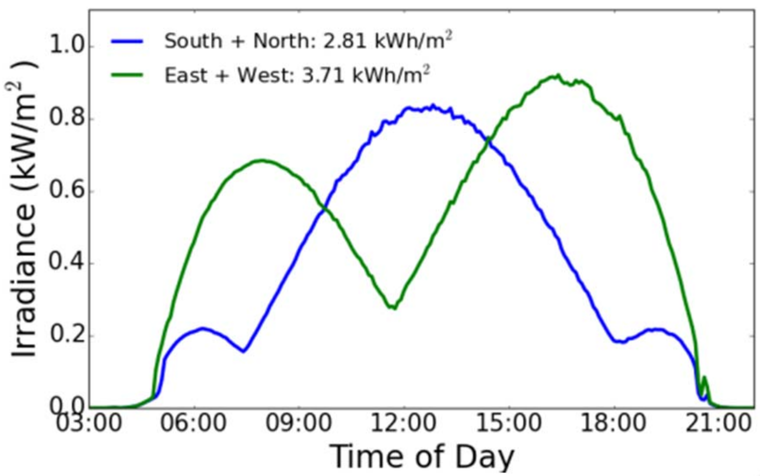
- ~100% yield compared to south-facing
- Noon peak shaving
- "rectangle" solar power generation
- Noise barriers, fences, ….

Bifacial Energy gain in kWh/kWp

Depends on:

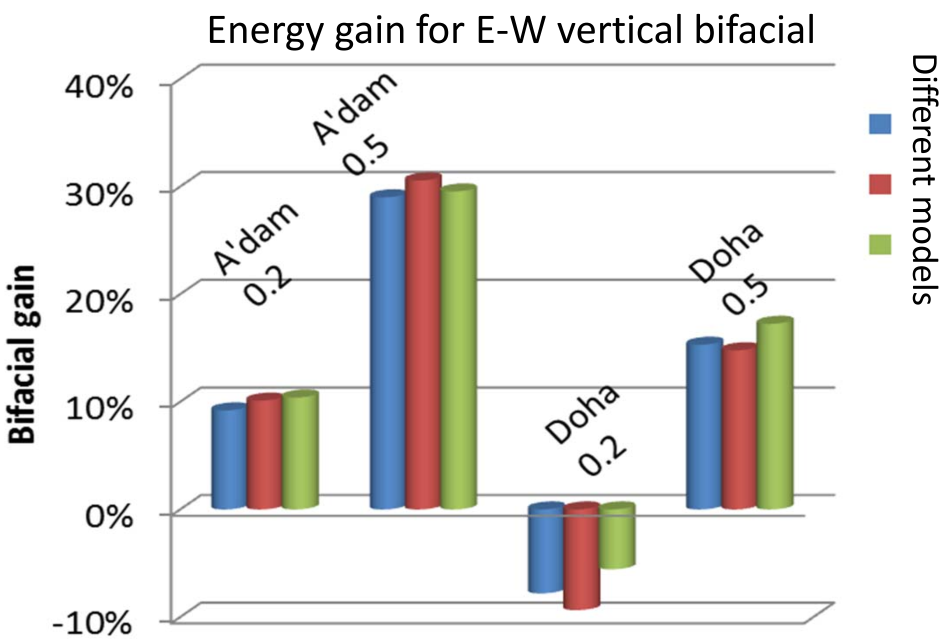
- reflected light (albedo)
- diffuse light
- installation and
- geographic conditions …… And the rear efficiency of the module itself!



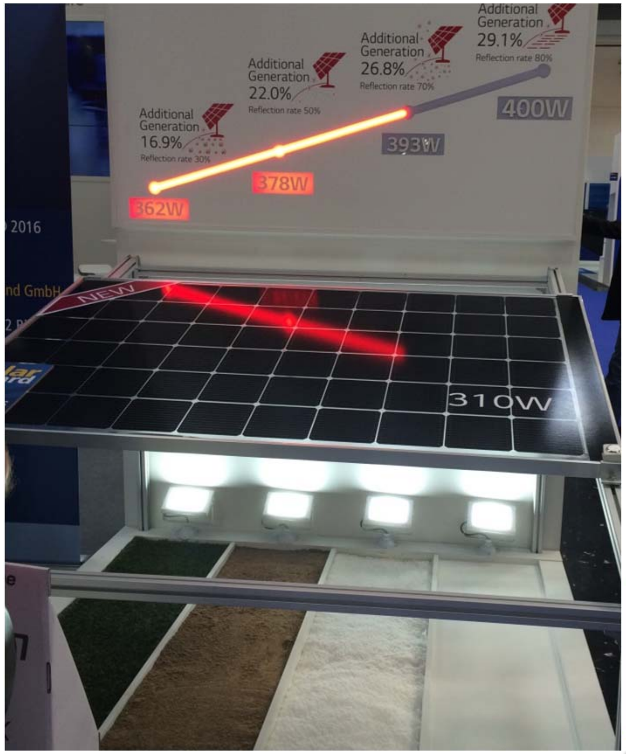


Example: influence of albedo and location

- Simulations with different location and albedo of 20% and 50%:



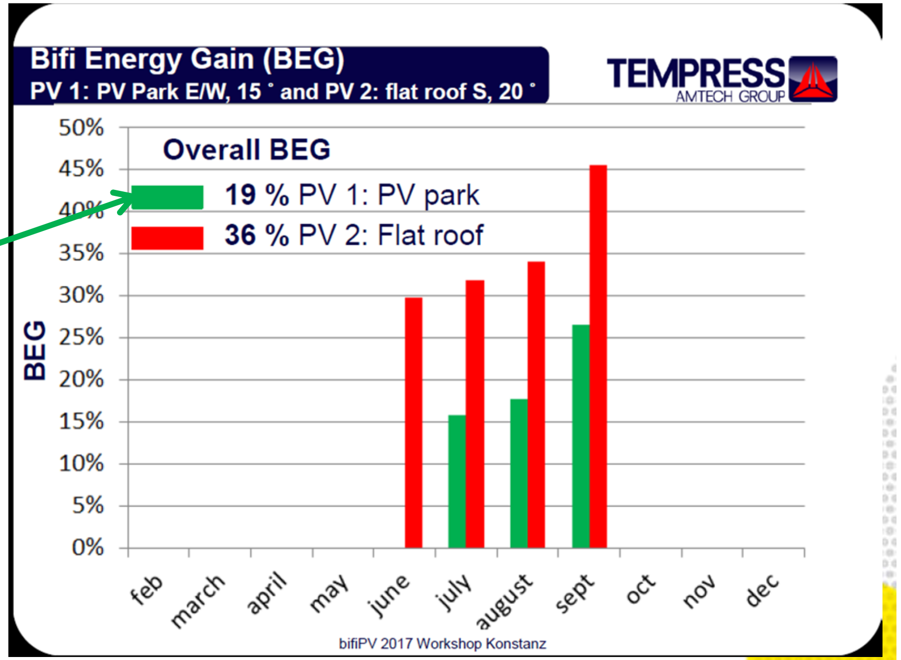
- Test setup with different albedo:



LG, Intersolar 2016, Hamburg

Example: actual gain in kWh/kWp

Installed in June 2017
400 kW on 3300 m²



W. Vermeulen, 4th bifiPV workshop, Konstanz, Germany, 2017

Bifacial PV – now and in the future

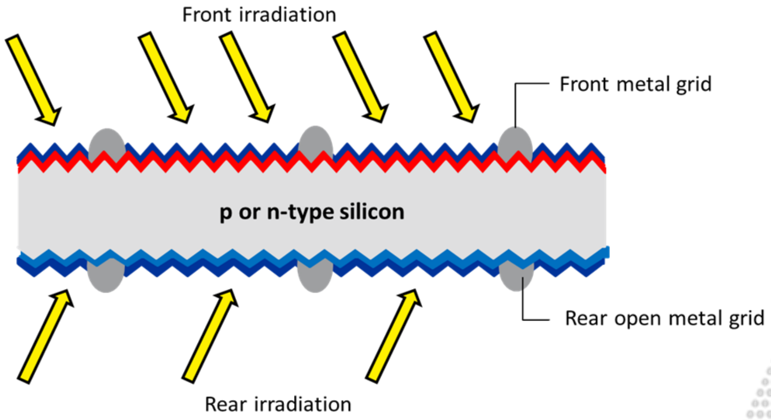
- Bifacial PV specifics
  - Bifaciality factor
  - Bifacial efficiency
- Current state of the art
  - Cell concepts
  - Metallization challenges
  - Modules in production
- Future
  - New and innovative cell/module designs
  - Novel system applications

What is a bifacial solar cell?

- Simultaneous and efficient conversion of light that illuminates the solar cell from the **front side** as well as from the **rear side** into electricity

- The rear efficiency can be **>90%** of front efficiency

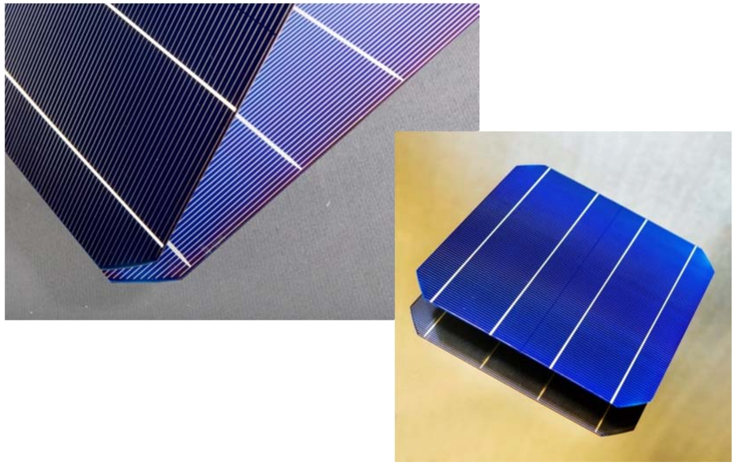
- Using the addition energy yield, a **very low LCOE** can be realized in bifi system



Characteristics bifacial solar cells: bifaciality factor φ

φ = ratio between front and rear response

$$\varphi_{\eta} = {}^{\eta_{rear}}/_{\eta_{front}}$$



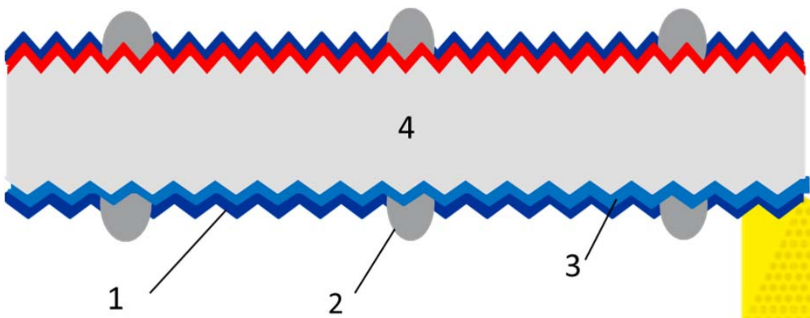
φ <1

bifacial solar cells are typically not symmetrical

- Emitter/BSF
- Metal patterns optimized for front efficiency

Main parameters influencing φ:

1. Rear texture and ARC
2. Metal coverage on the rear side
3. Rear side (BSF) doping and passivation
4. Base resistivity and lifetime



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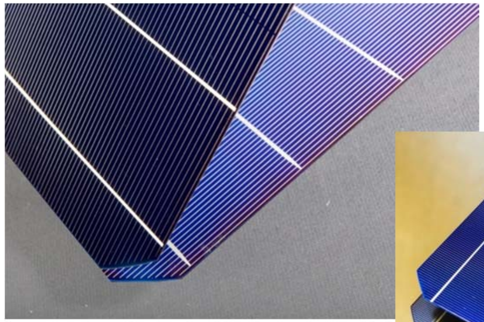

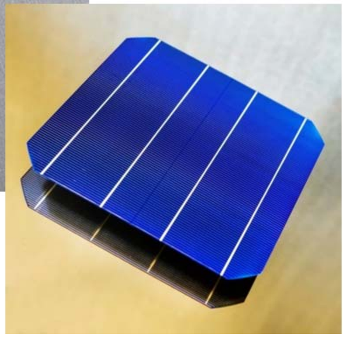

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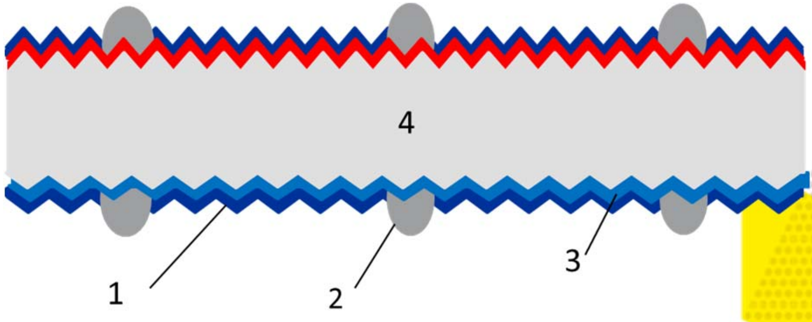
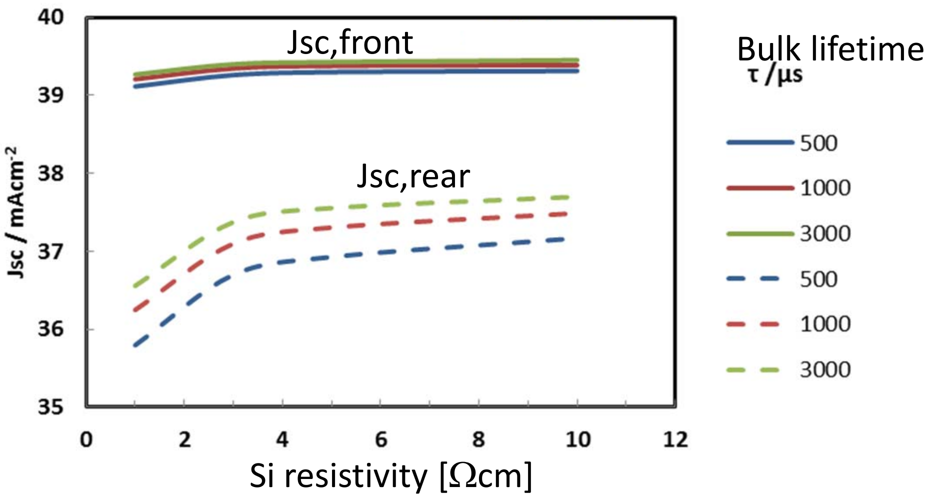


Effect of bulk resistivity and lifetime on bifaciality

Atlas simulations on n-type bifacial solar cells

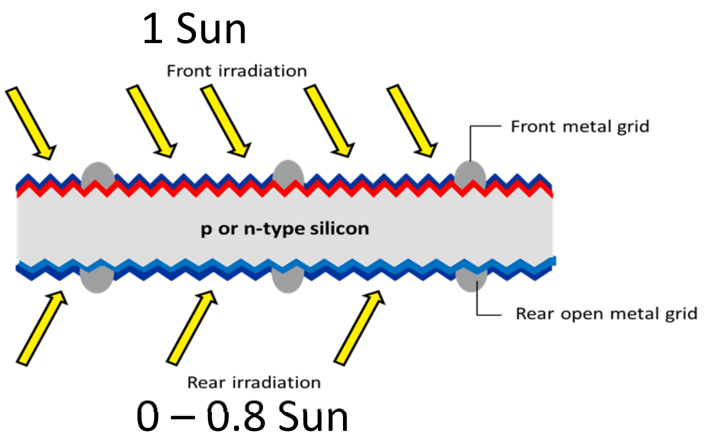
- φ_{Voc}, φ_{FF}: (close to) unity → φ_{eta} = φ_{Jsc}

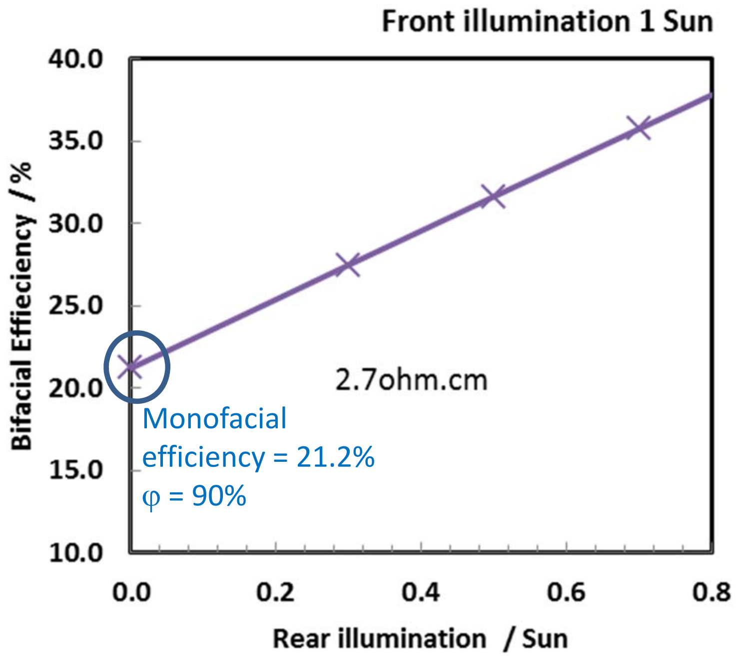


- J_{sc}: metal fraction + transport of carriers from illuminated side to other side
- High resistivity: lower N_D → less recombination → higher bifaciality
- Higher bulk lifetime → less recombination → higher bifaciality

Bifacial efficiency

1000 W/m² front & varying rear irradiation on bifacial n-PERT cell:

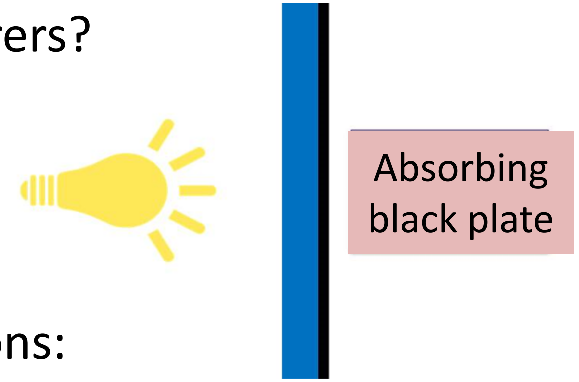




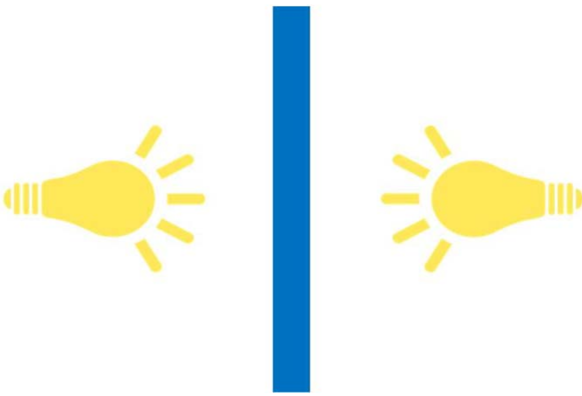
Bifacial solar cells are a great way to increase the efficiency !

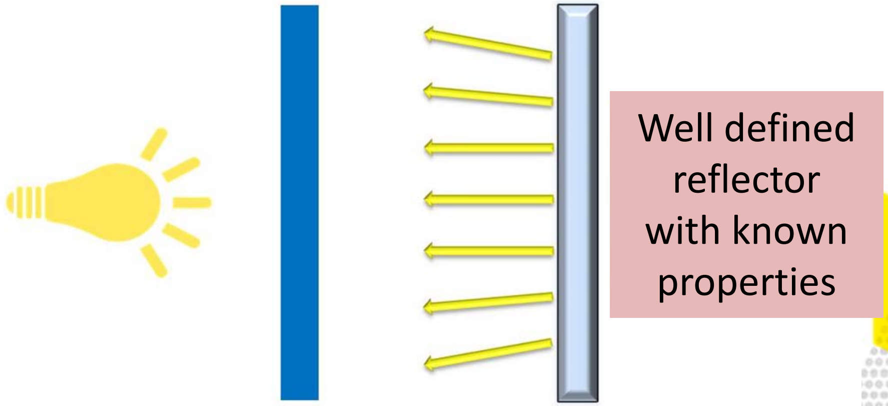
How to determine bifacial efficiency?

- Nameplate rating for manufacturers?



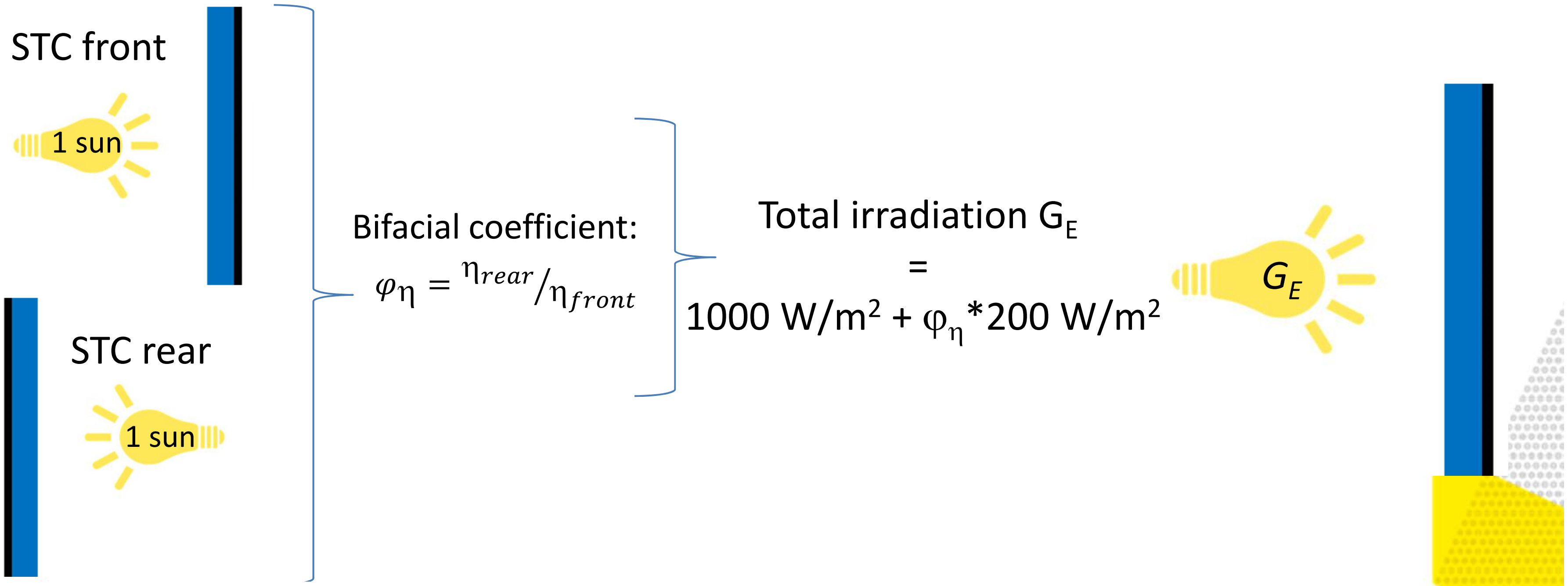
- Other options:





Standardization ongoing

- IEC 60904-1-2: I-V measurement of BiFi devices
- **Compensated current method**: report efficiency$_{BIFI20}$

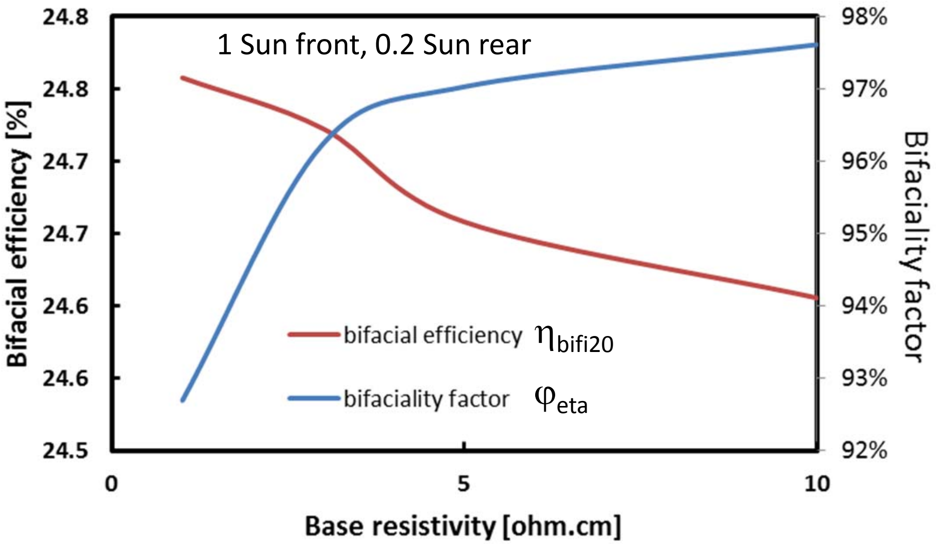


Details: V. Fakhfouri, 4th bifiPV workshop, Konstanz, Germany, 2017

(also efficiency$_{BIFI10}$ is used)

Trade off bifacial efficiency and bifaciality in n-PERT

- Low base ρ: improved lateral conductivity → increase in FF → High η_{bifi}
- High base ρ: reduced rear recombination → increase in φ_{eta}



Cell design can be adapted for efficiency or bifaciality depending on module / application use

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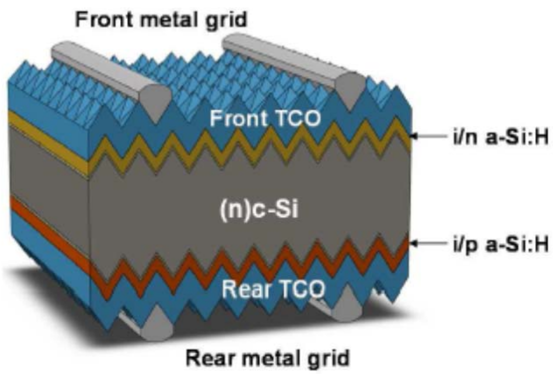
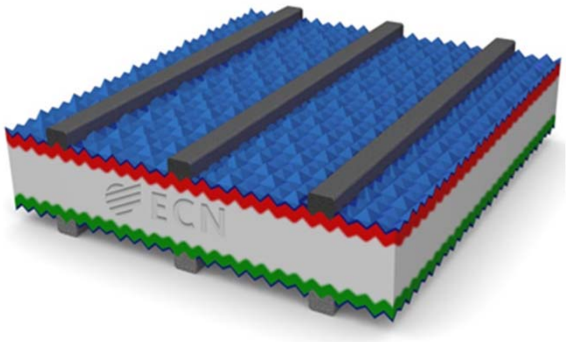
Bifacial solar cells: 3 different flavours, all x-Si based

n-type: naturally bifacial due to rear doping

HJT

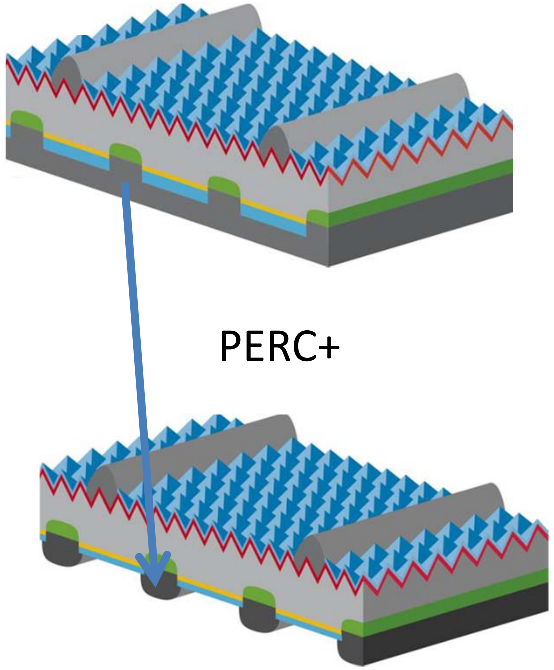


PERT



p-type: full Al rear into Al fingers

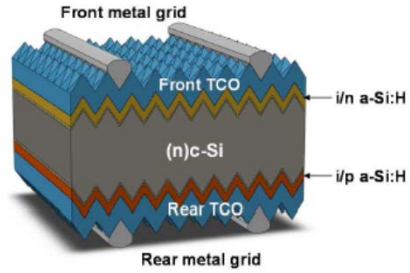
PERC

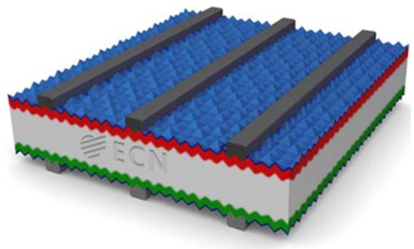


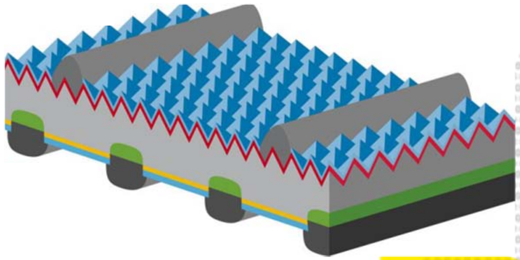
ecn.nl

Different designs for bifacial cells

Selection of front and rear contacted bifacial cells			
technology	SP + Standard BB	TCO / plating No BB (grid touch)	bifaciality
n-type			
HJT		>23.4% (MB)[1]	>95%
n-PERT	21% (ECN) 21.7% (Industry)	22.8 (imec)[2]	>95%
p-PERC+	21.6% (ISFH)[3]	22.1% (ISFH)4	80%
p-type			







1: B. Strahm et al., 7th International Conference on Crystalline Silicon PV, Freiburg, Germany (2017)
2: R. Russell et al., 33th EUPVSEC, Amsterdam, NL (2017)
3: T. Dullweber et al., 31st EUPVSEC, Hamburg, Germany (2015)
4: T. Dullweber, Bifi workshop 2017

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Selection of front and rear contacted bifacial cells			
technology	SP + Standard BB	TCO / plating	bifaciality
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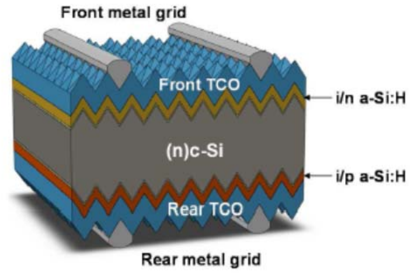
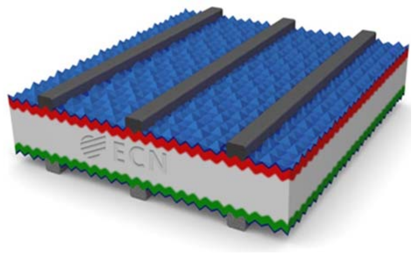
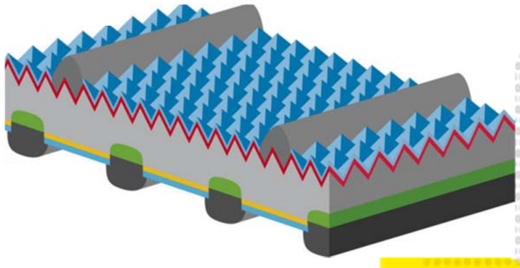
High T			







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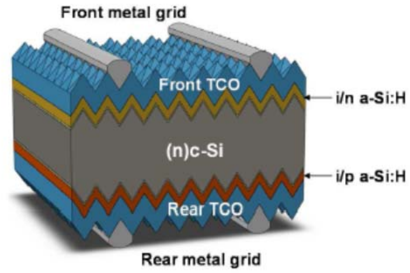

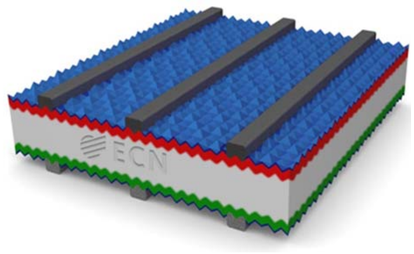

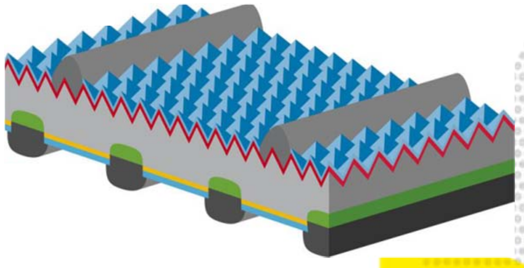

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Metallization: specifics, strengths and challenges

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Specifics	TCO + Low T Ag paste or plating front and rear	Ag/Al paste front and Ag paste rear	Ag paste front Laser opening + Al paste rear

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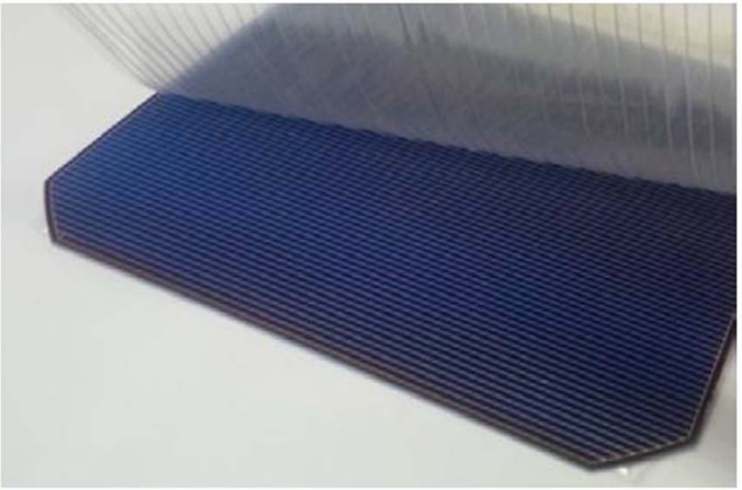
Solutions	Smartwire (MB) or conductive adhesives	Selective emitters, reduce emitter area	Multi-Busbar (>5BB) Pattern recognition

Consequences for module design

- HTJ → smartwire
- PERC+ → multiwire

MEYER BURGER

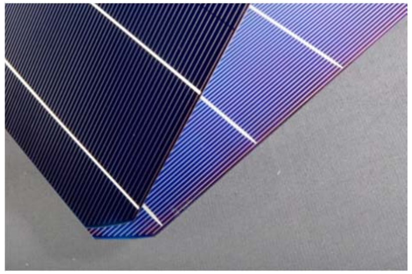


SCHMID
Expect Solutions

Current commercial bifacial cells & modules

Selection of PV companies working on different bifacial cell & module technologies[1]

technology	Eta	bifi						
HJ	22 – 23.5%	>95%	Sunpreme	3sun	Hanergy	Panasonic	Jinergy	
n-PERT	21 - 22%	>90%	Jolywood	Yingli	Adani	Linyang	Trina	LG
p-PERC+	21 – 21.6%	70%	SolarWorld	NSP	LONGi	Trina		


Heterojunction, n-PERT and p-PERC+ are adopted by industry

1: S. Chunduri, M. Schmela, Bifacial Solar Module Technology, 2017 Edition, TaiyangNews

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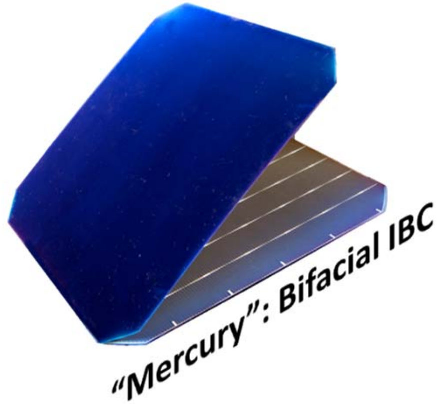
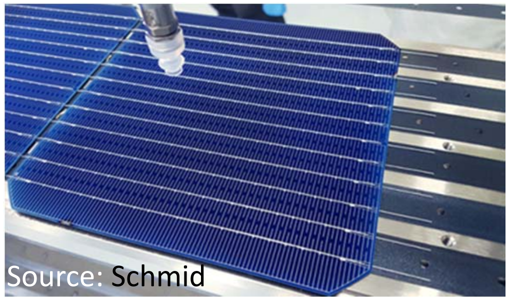
Novel concepts: Bifacial back contact

- Several examples published
  - ECN's n-MWT[1]
  - ISC's Zebra IBC cell[2]
  - ECN's Mercury IBC cell[3]

- Bifaciality: 75% - 83%

- Interconnection – **so far R&D**:
  - standard soldering or gluing of ribbons
  - conductive backsheet
  - MultiWire or SmartWire

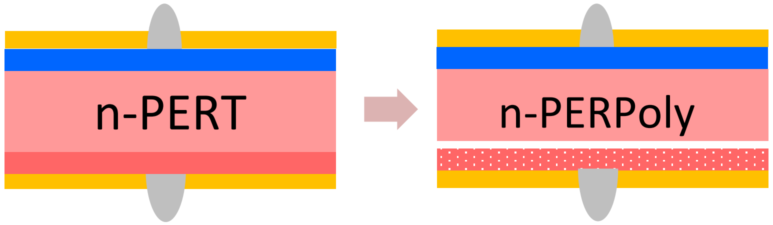




1: A. Gutjahr et al., 30th EUPVSEC, Amsterdam, NL (2014)
2: G. Galbiati et al., IEEE J. Photovolt., 3, pp. 560-563, (2013)
3. N. Guillevin et al., 33th EUPVSEC, Amsterdam, NL (2017)

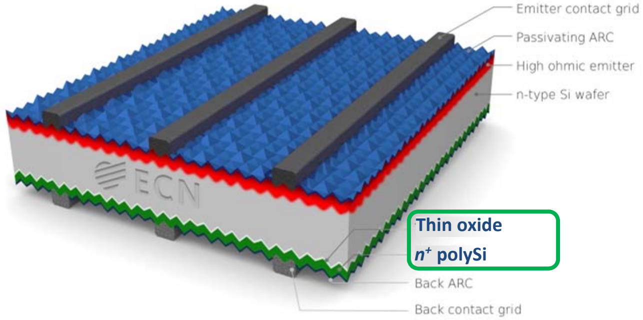
Novel concepts: Industrial carrier selective contact cell

- n-PERT + n+poly-Si rear ➔ ECN's PERPoly cell
- Efficiency potential: up to 23%



Poly thickness	iV_{oc} (mV)	V_{oc} (mV)	J_{sc} (mA/cm²)	*FF* (%)	*η* (%)	Bifaciality
80 nm	697	676	39.7	80.0	**21.5**	**86%**
150 nm	693	675	39.6	80.4	**21.5**	**81%**

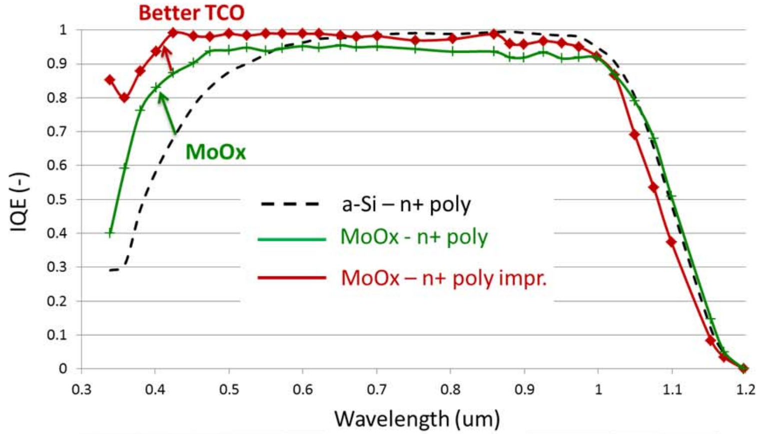
Passivated **E**mitter and **R**ear **Poly** cell

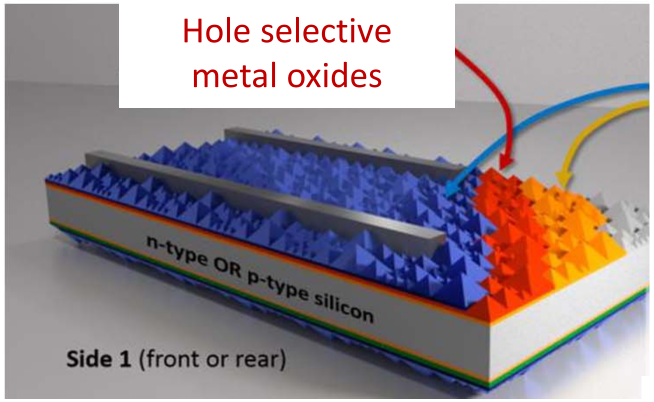


TEMPRESS AMTECH GROUP · LEVITECH · MEYER BURGER · TU/e Technische Universiteit Eindhoven University of Technology · TU Delft Delft University of Technology · UNIVERSITY OF TWENTE. · ECN

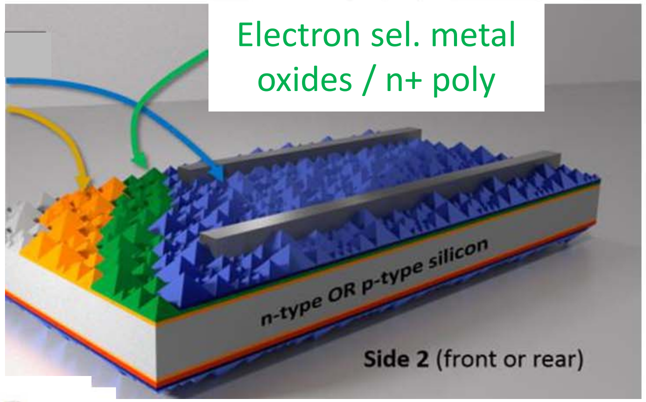
Novel concepts: transparent metal oxide contacts

- Bifacial solar cell with transparent & highly selective contacts at both sides
  - Hole selective: MoO_x, WO_x
  - Electron selective: TiO_x, ZnO_x:Al
- First results at ECN: Moly-Poly cell with
  - Eta 18.1%, clear gain in blue response





Supporting layers:
TCO
Oxide interface

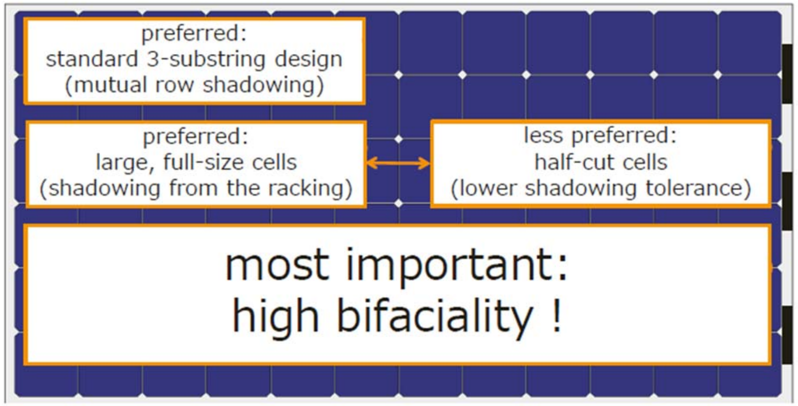


LEVITECH SolMateS TU/e Technische Universiteit Eindhoven University of Technology FOM Institute AMOLF TUDelft Delft University of Technology ECN

Bifacial PV Applications in 2017

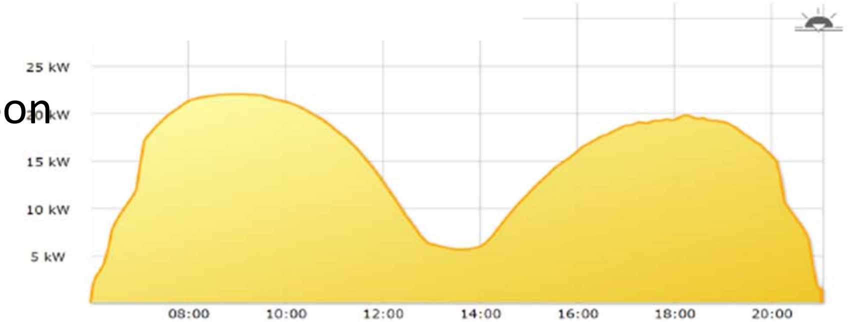
1. Chile: La HORMIGA power plant: 2.5 MWp
2. US: SUNPREME power plant: 12.8 MWp
3. China: Jolywood / Xintai power plant: 40 MWp
4. China: Yingli / Datong City power plant: 50 MWp

Novel applications: Agri PV



Remaining grass below modules

- Bifacial energy gain 10%: proven
- Electricity production in morning & afternoon
  - Better matching with electricity need
  - Higher electricity price



H. Hildebrand, 4th bifiPV workshop, Konstanz, Germany, 2017

Novel applications: PV on water

- Use of unexplored, available space
- Contribute to natural ecosystem
- Bifacial energy gain up to 30%
- Systems can be south facing, or vertical east-west
- Ideal for matching electricity generation with consumption peaks!

R. Kreiter, 4th bifiPV workshop, Konstanz, Germany, 2017


• All advanced xSi cell concepts can be made bifacial
• Bifacial PV is a great way to increase power and efficiency
• The flexibility of bifacial PV offers unique opportunities for PV in infrastructure, agriculture or on water
• Heterojunction, n-PERT and p-PERC+ are all adopted by industry
• Next generation bifacial concepts in R&D & test fields
• **Bifacial PV significant in NL and here to stay!**
http://www.fototavling.nu/ExternaSkript/bidrag/kontraster/large/large_catch-the-sun-4311.jpg

Thank you for your attention!

Thanks to the ECN bifacial team:

Bas van Aken, John Anker, Paula Bronsveld, Anna Carr, Bart Geerligs, Astrid Gutjahr, Gaby Janssen, Martien Koppes, Eric Kossen, Ji Liu, Jessica Lu, Jochen Loffler, Agnes Mewe, Bonna Newman, Nienke Riezebos, Ingrid Romijn, Maciej Stodolny and Kees Tool

http://www.fototavling.nu/ExternaSkript/bidrag/kontraster/large/large_catch-the-sun-4311.jpg

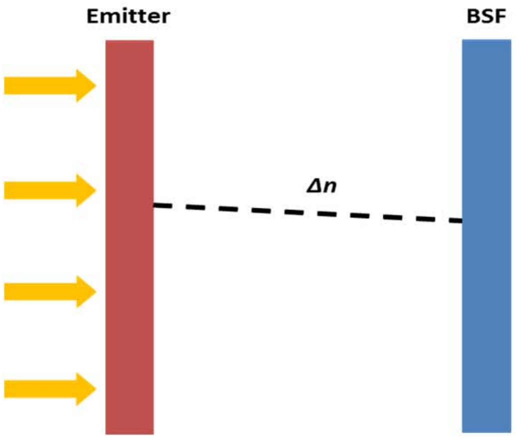
Additional slides

Bifaciality in n-PERT – dependency on BSF

BSF:

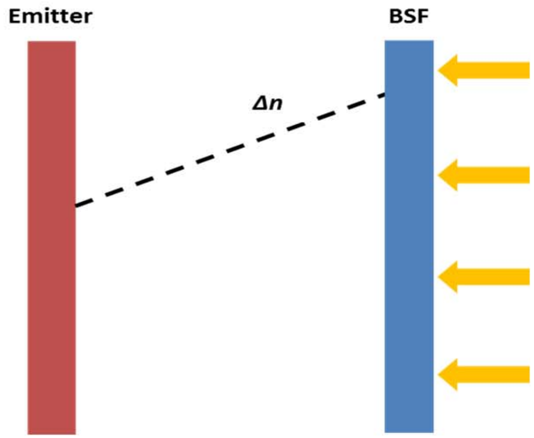
- Lateral conductivity → reduced metallization on rear
- Free carrier absorption
- Recombination (J_r)

$$J_{recomb} = J_{0,BSF} \frac{\Delta n \cdot (N_D + \Delta n)}{n_i^2}$$



Front illumination:

- Charge carrier transport to rear is field driven



Rear illumination:

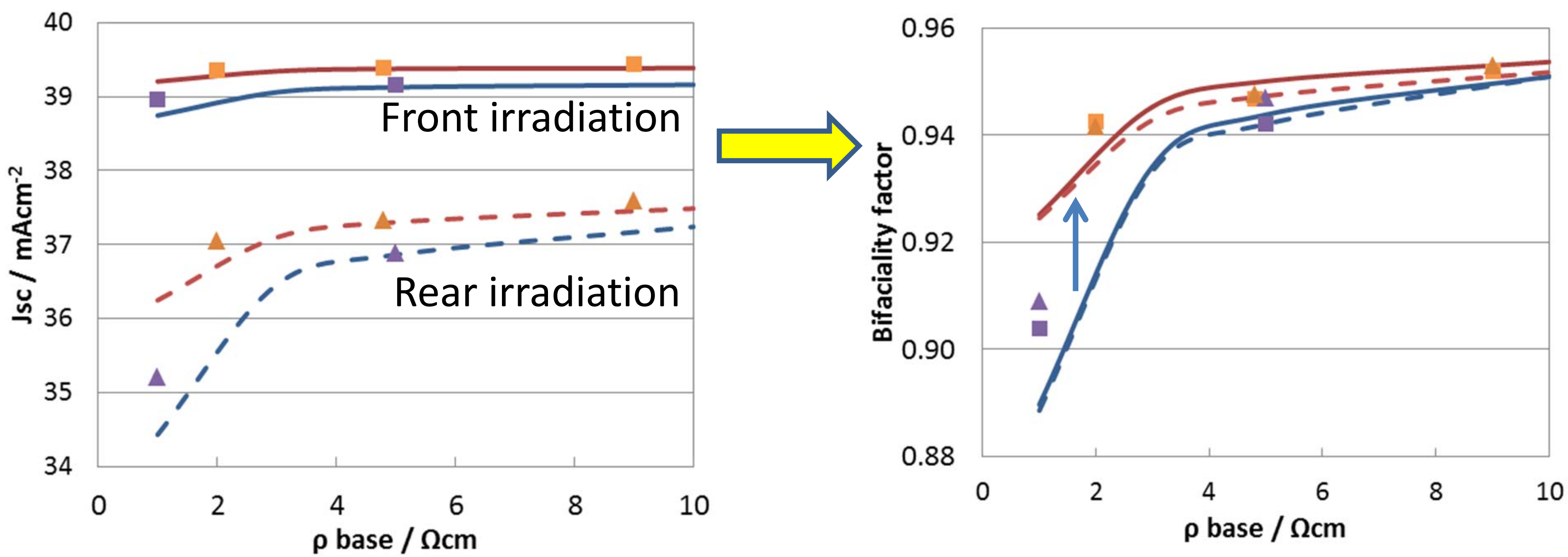
- Charge carrier transport to front is diffusion driven → high Δn builds up near BSF

→ **Enhanced recombination**

Effect of BSF

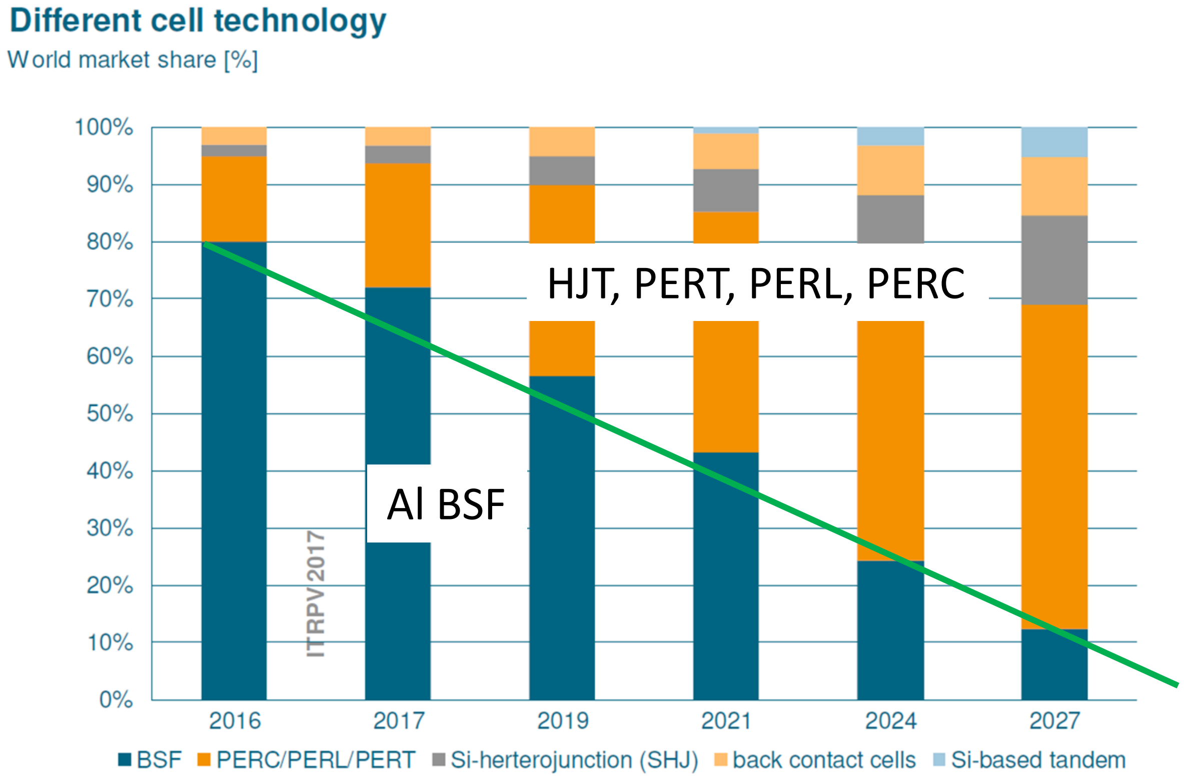
Measurement data from n-Pert cells; Atlas simulations Gaby Janssen

- Standard BSF
- Improved BSF, identical metallization



Improved J_{0BSF} (less Auger and surface recombination) → improved bifaciality

Bifacial solar cells = the future



All advanced solar cells can be made bifacial

ecn.nl

Bifacial solar cells

- 1960: first description of bifacial cell by H. Mori
- 1977: first bifacial lab cells, n+pn+ / n+np+
- 1980: use of albedo realized

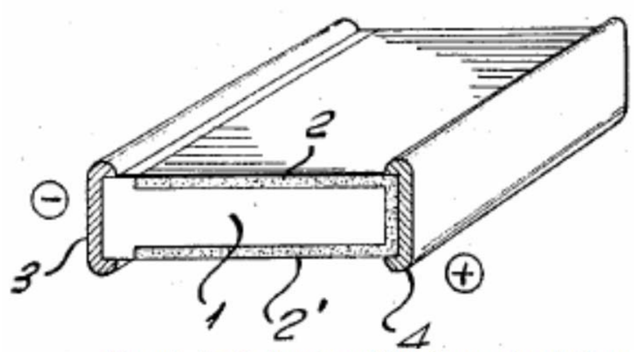


Figure 1. Double junction cell [1]. The numbers indicate 1: n-type silicon, 2 and 2': p-type emitter regions.

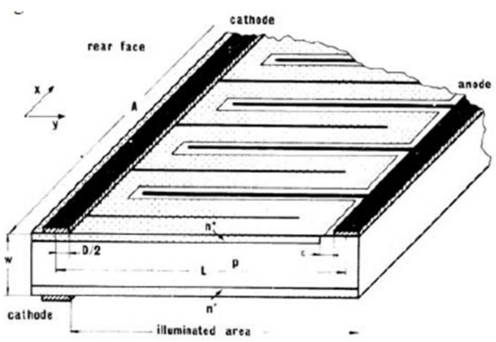


Figure 2. Double-junction solar cell, or Transcell [10].

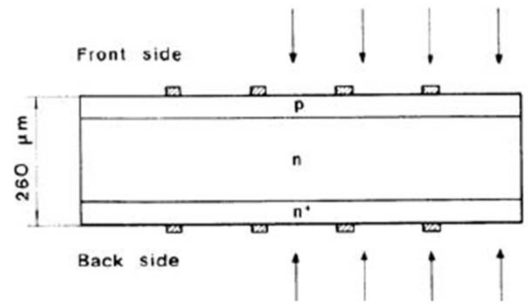
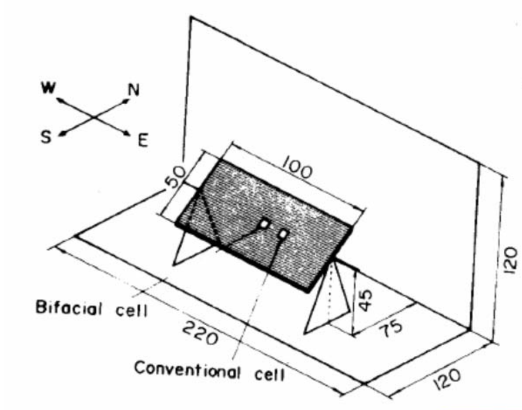


Figure 3. Bifacial Back Surface Field solar cell [26].



Ref: A. Cuevas, "early history of bifacial solar cells", 20th EUPVSEC 2005, Barcelona, Spain

Commercial bifacial solar cells:

- 2000: Bifacial HIT cells from Sanyo in production

→ Symmetric metallization for thin wafers

- 2004 - 2008: large scale PV industry takes off….

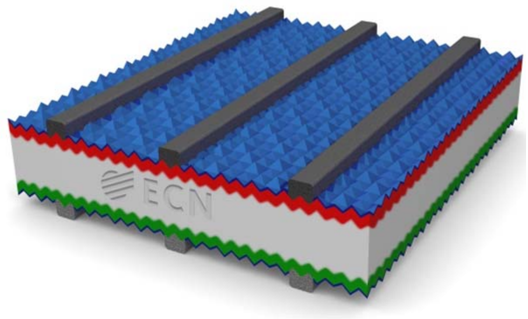
→ With monofacial cells and modules

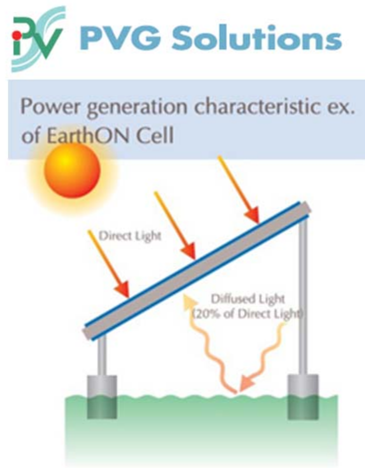
- 2010: Yingli commercializes ECNs n-Pasha cells[1]

→ Applied in monofacial modules

- 2011: PVGS starts with EarthOn technology[2]

→ Applied in bifacial modules





1: A.R. Burgers, 26th EUPVSEC, Hamburg, Germany (2011)
2: S. Goda, 11th CSPV, Hangzhou, China (2015)

Bifacial modules

- 1997: first application of bifacial PV modules in sound barriers[1]
- 2003: novel applications of bifacial solar cells in sun-shading elements[2]

1: http://www.tnc.ch/en/power-instead-noise-photovoltaic-noise-barriers-1
2: R. Hezel, "Novel Applications of Bifacial Solar Cells", Progress in PV: Res and Appl. ***11****, p549-556, 2003*

Bifacial cells predictions for the future

- First in appearance in ITRPV roadmap of 2017
- Bifacial cells become more and more prominent in the PV world
- Advanced cell concepts become industrialized – all can be made bifacial

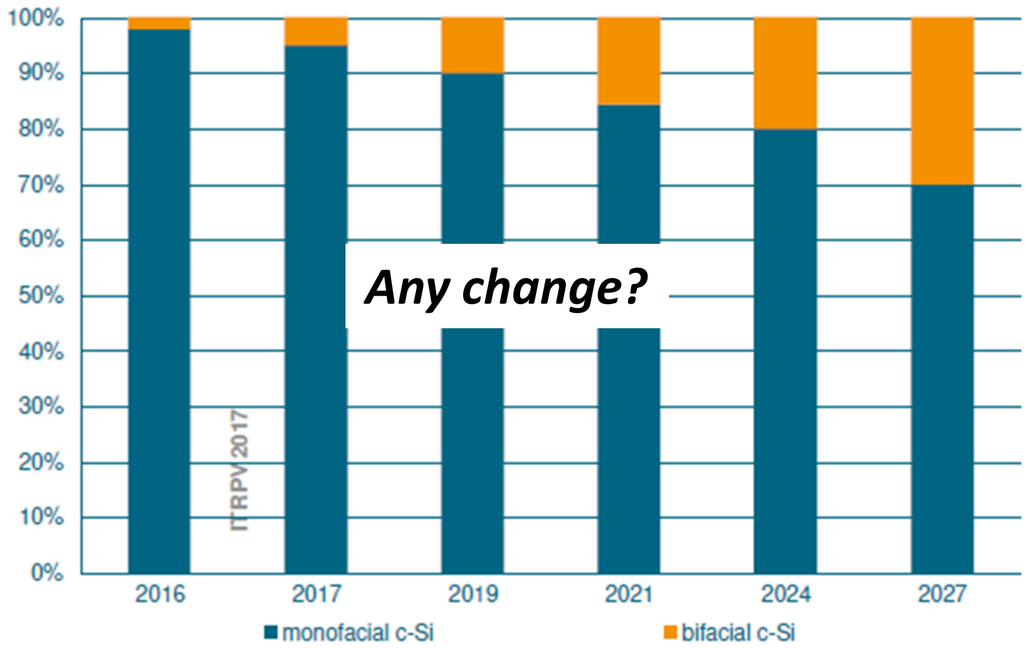


Fig. 29
Worldwide market shares for bifacial cell technology.

Bifacial cells predictions for the future

- Introduction slower then expected, but prediction becomes even more positive!