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ITRPV | International Technology Roadmap for Photovoltaics

VDMA

Trends in c-Si PV -
Manufacturing Challenges for the PV Powered Future
– a review of the ITRPV 10th Edition

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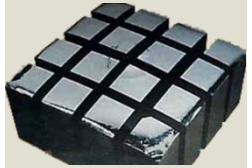
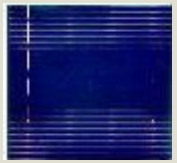
Hanwha Q Cells GmbH, Germany
10th World Solar Congress,
October 31 2019, Shanghai, China

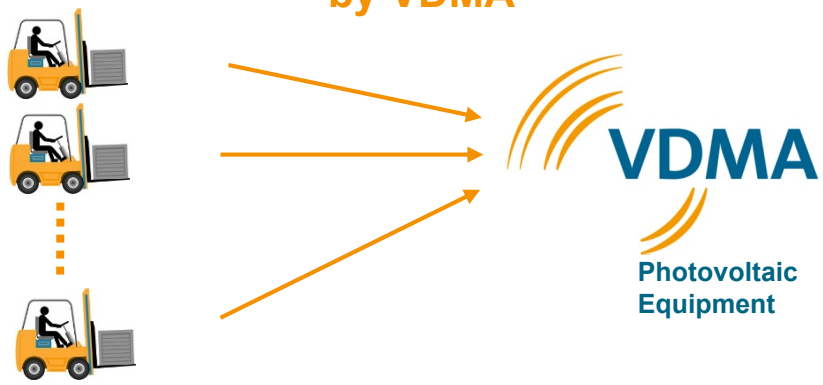
ITRPV – Methodology / Statistics

10th edition: 55 contributors from Asia, Europe, and US (incl. maturity report)

SILICON	CRYSTAL.	WAFER	CELL	MODULE	SYSTEM
					

Figures o/a: 90 (71)
Materials: 19 (16)
Processes: 29 (21)
Products: 20 (14)
PV systems: 9 (8)

Participating companies → **Independent data collection / processing by VDMA** → **Review of data Preparation of publication → regional chairs** → **Next ITRPV edition**



- Chairs US
- Chairs PRC
- Chairs TW
- Chairs US

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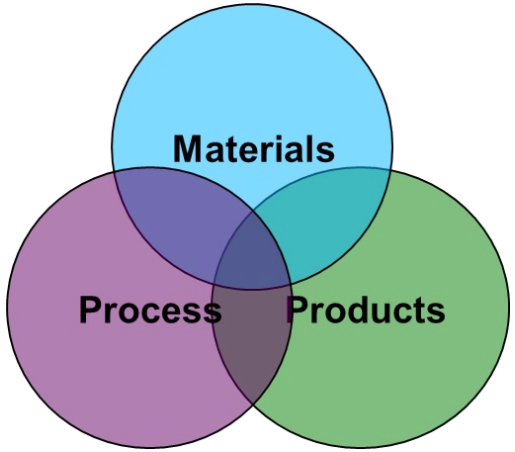
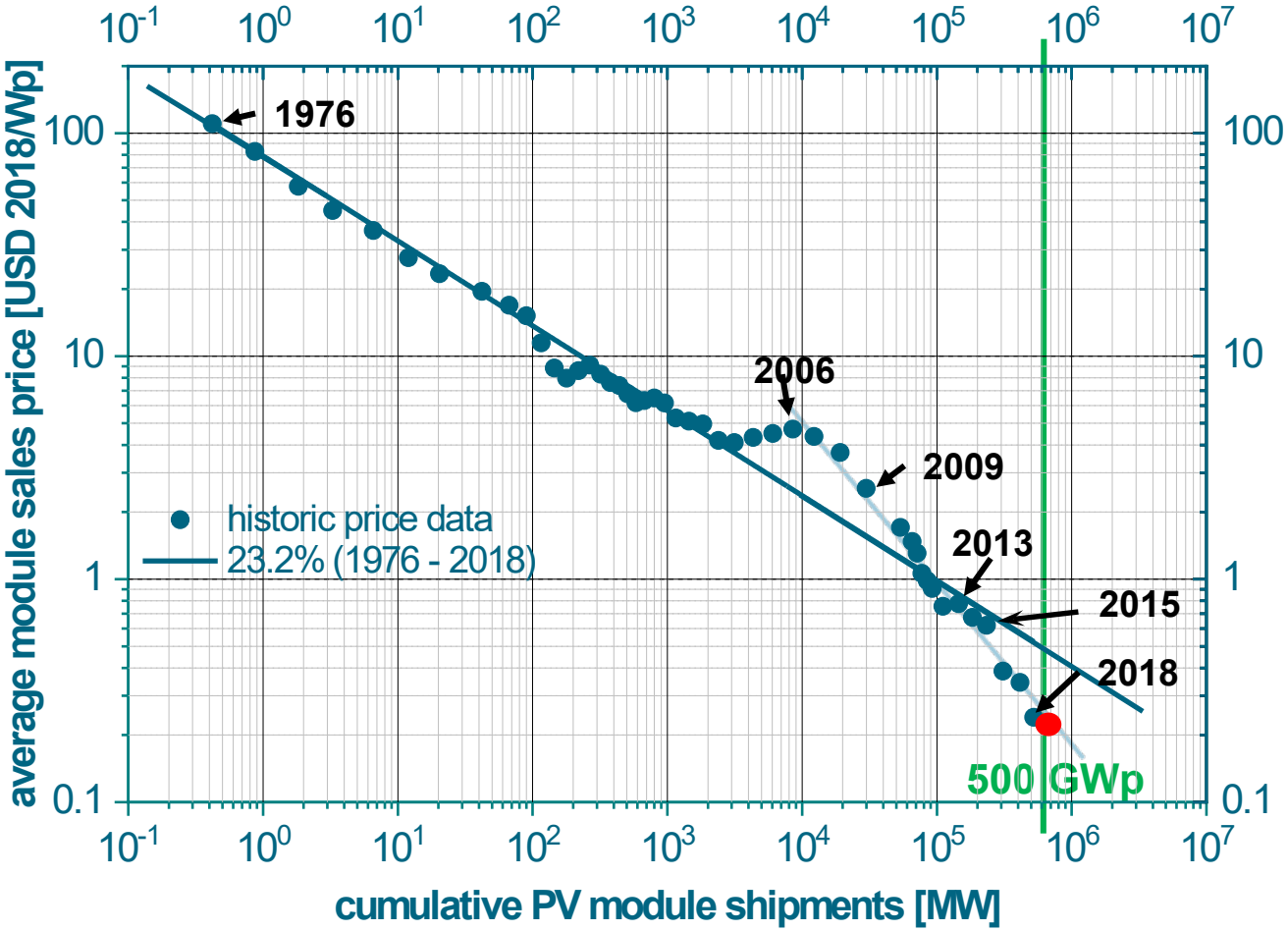


Parameters in main areas are discussed → Diagrams of median values

PV learning curve – Module



Shipments /avg. price at years end:

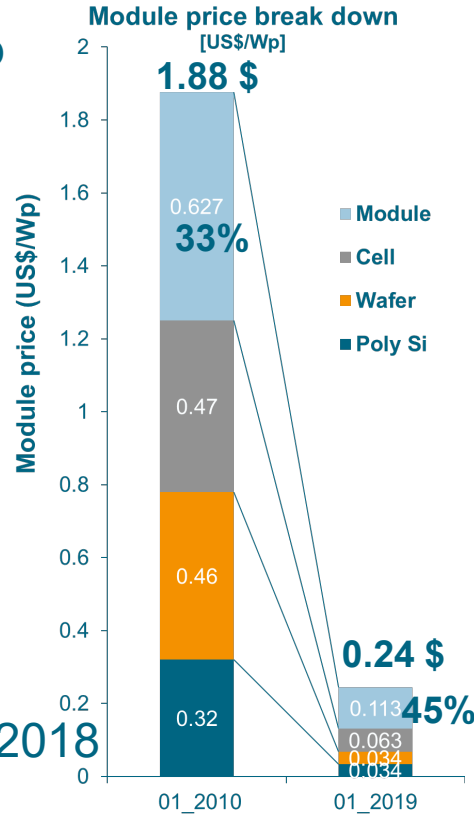
2017: 105 GWp / 0.35US$/Wp
2018: 109 GWp / 0.24 US$/Wp
2019: ≥120 GWp est.

2018 o/a shipment: ≈ 523 GWp
o/a installation:≈ 504 GWp

0.5 TWp milestone passed!

LR ≈23 % (1976 …. 2018)
LR ≈40 % (2006 …. 2018)

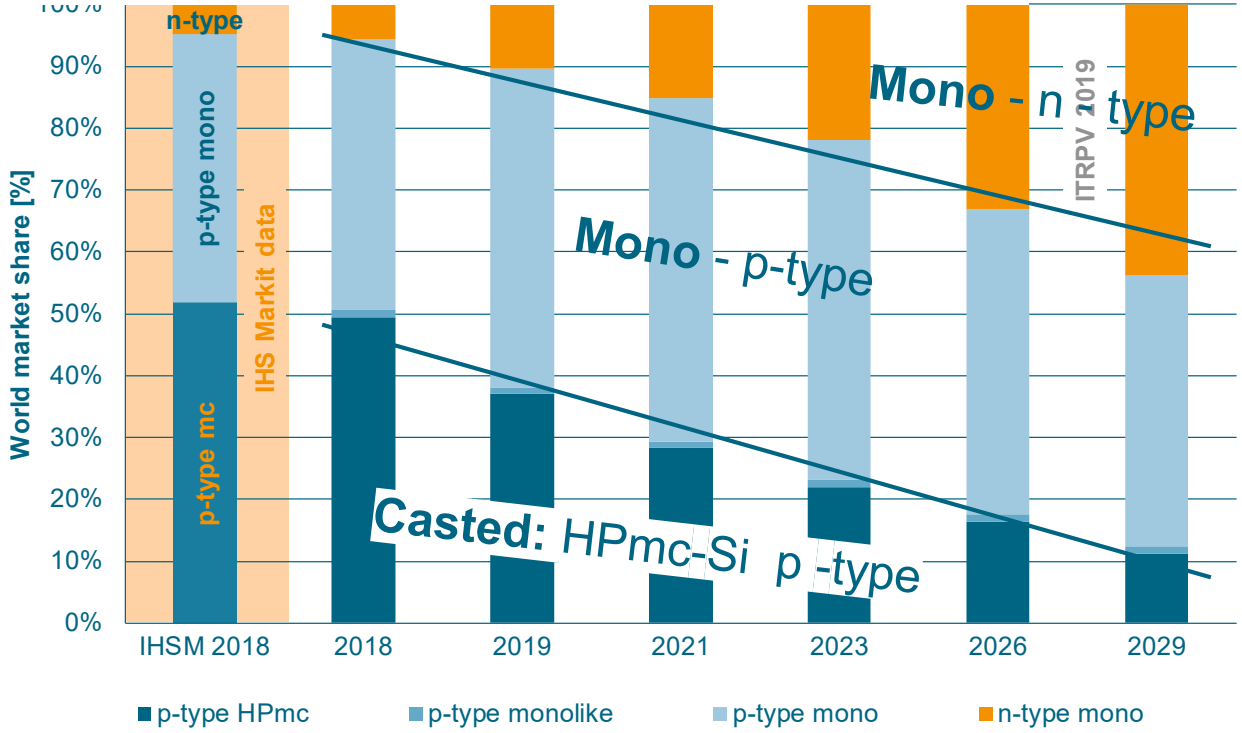
➔ ≈90% price reduction 2009 → 2018



→ High volume shipped with **huge** price reductions

Wafer: Product –market share of wafer type

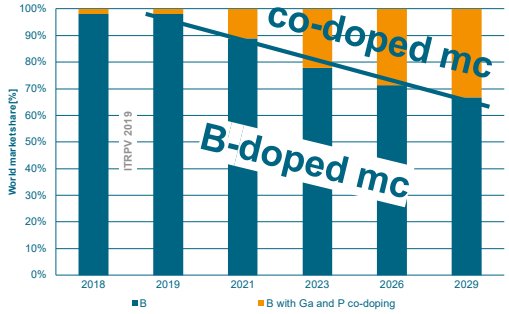
Trend: share of c-Si material types



→ **Mono will dominate** (further boost by n-type)

- **p-type material will stay mainstream until 2029**
  → base for p-PERC technology

- **casted-Si share shrunk to 50%:**
  → Dominance is gone,
  → p-type **HP** mc-Si is dominating
  → mono-cast @ 1%
  → **co-doping with Ga/P** will improve ingot quality

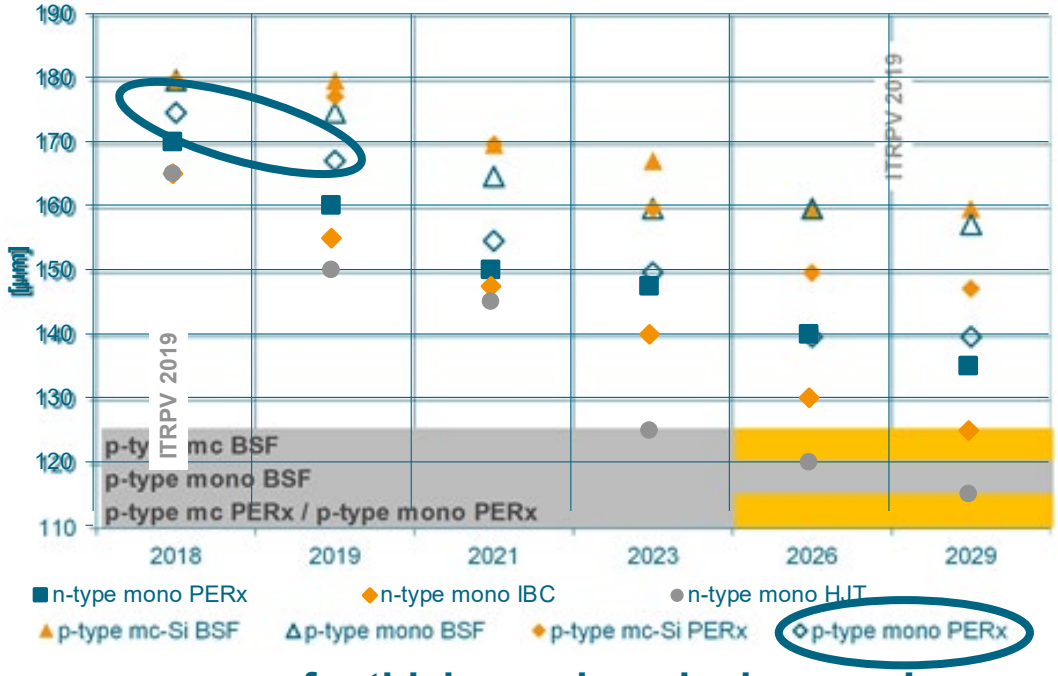


- **Mono technology will fast gain market share:**
  → n- + p-type ≈60% in 2019
  → n-type material share will increase (HJT, Topcon)
  → p-type will stay mainstream
  Ga doping expected to improve for mass prod.

- **2018 values in line w/ IHS Markit analysis**

Wafer: Process – crystallization / wafering technology

Trend: wafer thickness



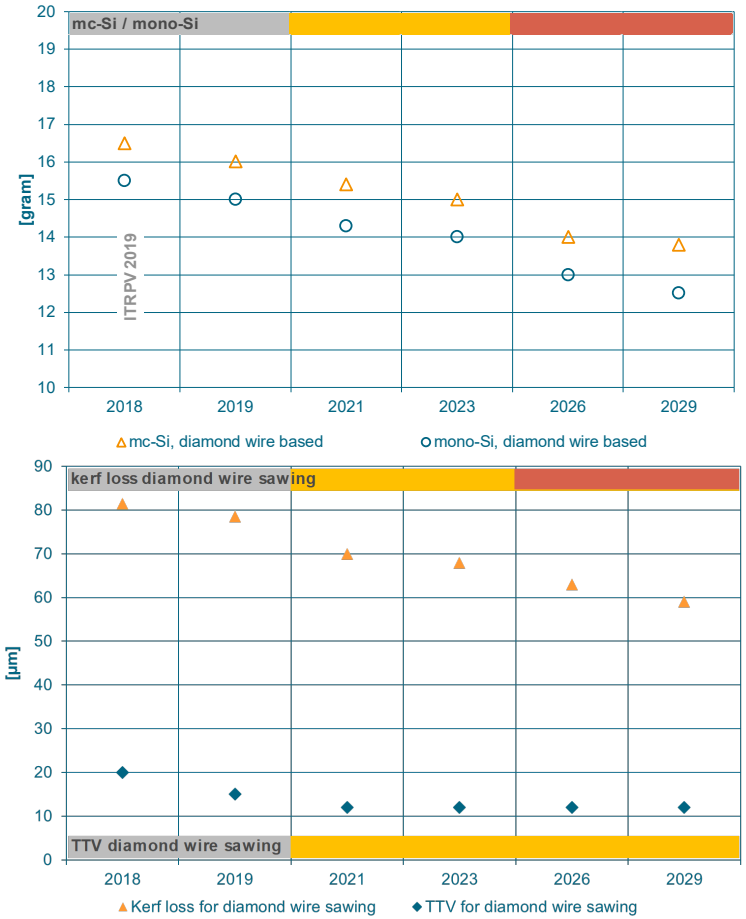
- **mono wafer thickness is reducing now!**

  2019 2029

  →p-type ≈170µm today, →140µm driven by PERx
  →n-type ≈150µm today, →115µm HJT leads
  →mc-Si still delayed

→ **Diamond wire** sawing is the only wiring technology

Trend: poly-Si utilization / kerf loss



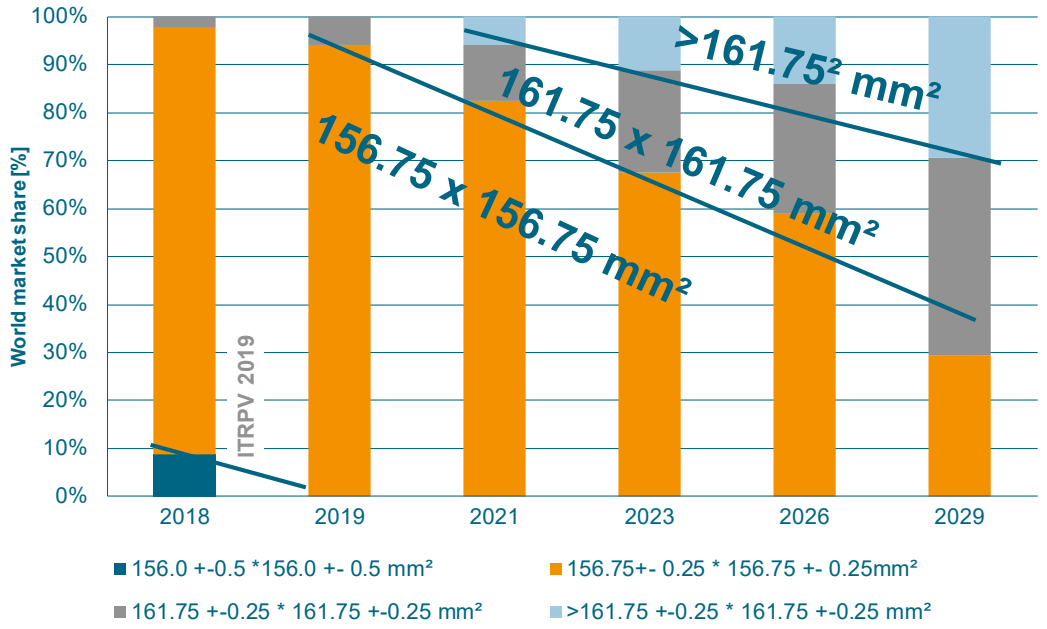
- Poly-Si utilization:
  → ≈ 16.5g / mc-Si wafer
  → ≈ 15.5g / mono wafer
  (156.75 x 156.75 mm²)

- kerf loss
  → ≈80µm 2019
  → ≈60µm 2029
- TTV
  → will improve to 10µm

Wafer: Product - market share of wafer sizes

Trend: mono-Si wafer size

→Mono will soon use ≥161.75x161.75mm²

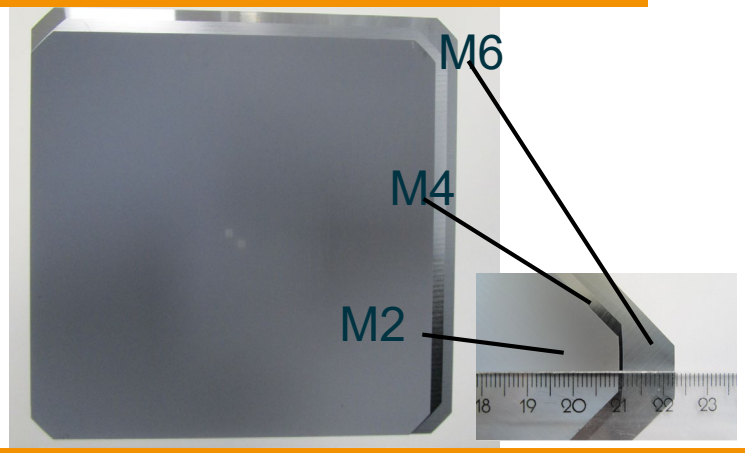


Implementation of new Wafer Size in Production

Wafer manufacturing mc-Si	158.75 * 158.75 (+/-0,25) mm²	in existing lines possible
	161.7 * 161.7 (+/-0,25) mm²	possible with upgrades
	≥ 166 * 166 (+/-0,25) mm²	possible with new lines
Wafer manufacturing mono-Si	158.75 * 158.75 (+/-0,25) mm² (full- & semisqu	in existing lines possible
	161.7 * 161.7 (+/-0,25) mm² (full- & semisqua	possible with upgrades
	166 * 166 (+/-0,25) mm² (semisquare)	possible with upgrades
	≥ 166 (+/-0,25) mm²	possible with new lines
Cell manufacturing	158.75 * 158.75 (+/-0,25) mm²(full- & semisqu	in existing lines possible
	161.7 * 161.7 (+/-0,25) mm² (full- & semisqua	possible with upgrades
	166 * 166 (+/-0,25) mm²	possible with new lines
	> 166 * 166 (+/-0,25) mm²	possible with new lines
Module manufacturing	158.75 * 158.75 (+/-0,25) mm²	in existing lines possible
	161.7 * 161.7 (+/-0,25) mm²	possible with upgrades
	≥ 166 * 166 (+/-0,25) mm²	possible with new lines

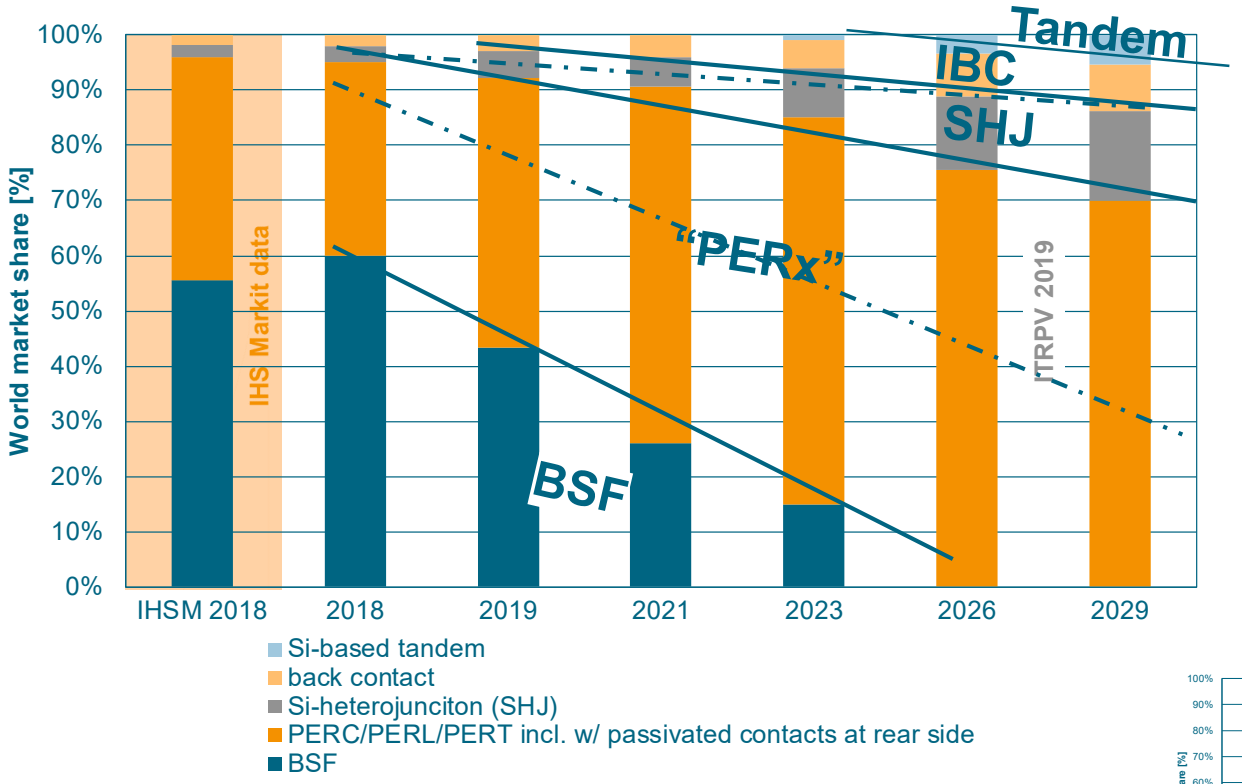
- **≥156.75 x 156.75 mm² (M2) is current mainstream!**
  →156 x 156 mm² - disappeared
  161.75x 161.75 mm² (M4) need upgrades of existing lines and larger modules
  166.75x 166.75 mm² (M6) need new tools → new fabs
  Ingot Ø 210 / 211 / 223m

➔ Standardization is required



Cell: Product – market share of cell technologies

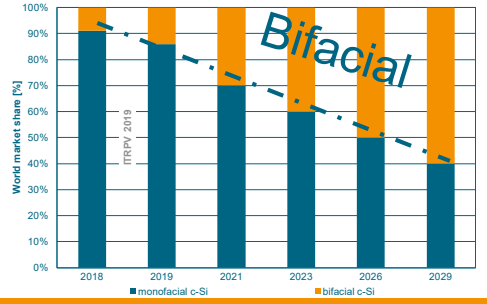
Trend: share of cell technologies



→ **"PERx" - technologies will dominate**
(2018 ITRPV data are close to IHS Markit)

- **BSF**
  → ≈40% share in 2019
  → focus on mc-Si BSF
  → **will disappear after 2025**
- **"PERx"** (incl. passivated contacts)
  → **concepts with diffused junction**
  → >50% share in 2019
  → **market mainstream in coming years**
  → on p- and n- type
- **Si- heterojunction (SHJ)**
  → ≈2% in 2018 → >15% in 2029
  → on n-type only
- **Si-Tandem** expected from 2023 onwards
- **Back contact concepts**
  → ≈2 % in 2018 → 10% in 2029

fit for **Bifacial**

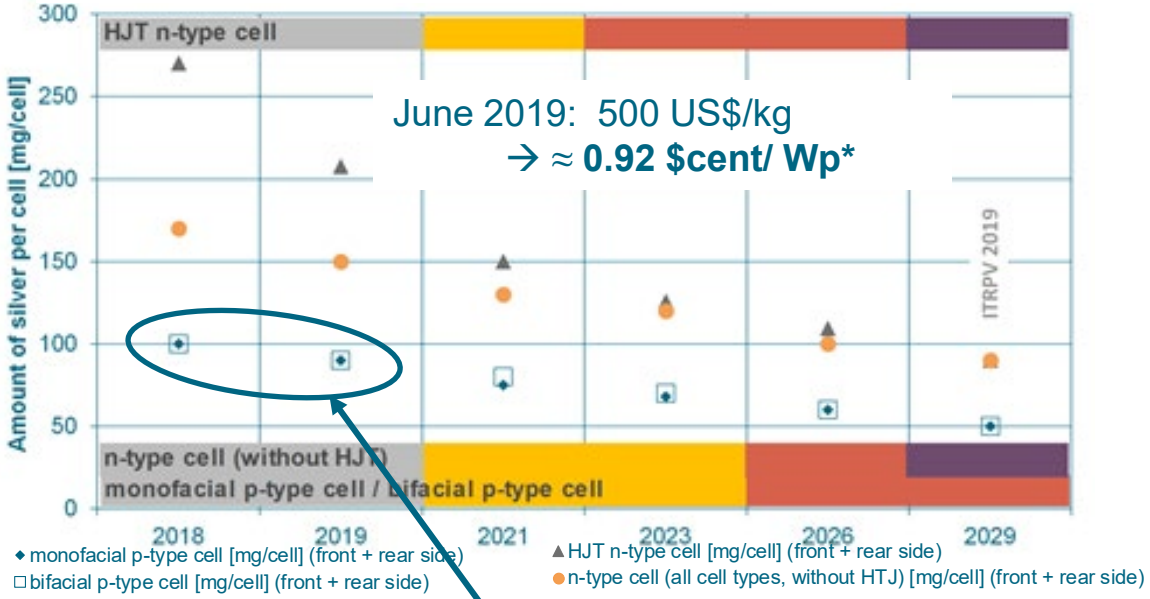


Bifacial cells will gain share
→ ≈15% in 2019
→ ≈60% in 2029

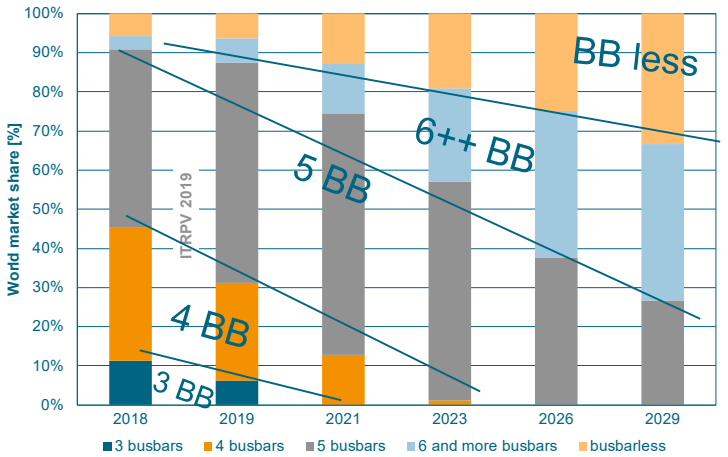
Cell: Process – metallization trends

2019: 20.25% x 0.987 (CTM) ≈ 4.91W/ cell *
→ ≈ 18.3 t / GWp
→ ≈ 1830 t @100GW = 6.2 % of world Silver market 2018**
Photography 1996: 40% of annual Silver market**

Trend: remaining Silver (predictions were met)



Trend: number of bus bars



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- **BB trend:**
  →5 BB+ is mainstream
  → 3/4BB will disappear
- Next steps: 9 / 12 BB
- **Bifacial trend:**
  Al- will also be reduced

Silver reduction will continue

→ 90mg Ag for p-type cells
→ n-type concepts need more Ag

Measures: - reduction of finger width → more bus bars
- finger width 40µm → 20µm in 2029
- Single print will remain mainstream

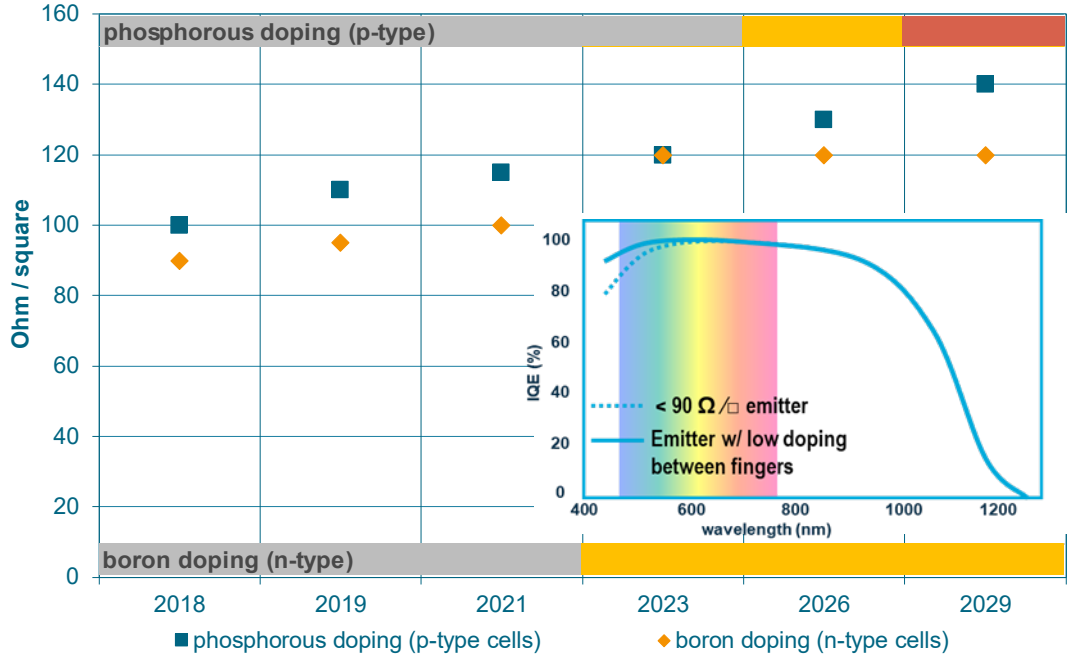
→ layout examples: (AIKO catalog)

* avg. module power 290W labeled ; ** Assumption ≈ 29,500 t / 1033 MOz 2018 Ag physical demand https://www.silverinstitute.org/publicatio

Cell: Process – emitter doping

Trend: emitter sheet resistance

Sheet resistance will increase further



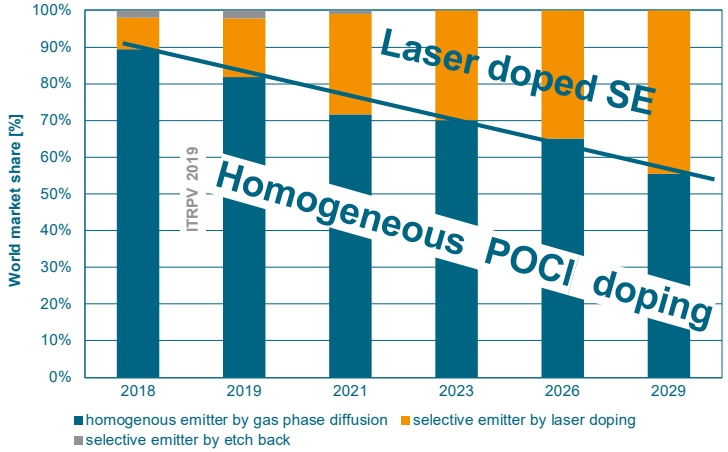
P-doping: 2018: 100 Ω/□ → 2029 140 Ω/□

→ selective emitter use will be intensified

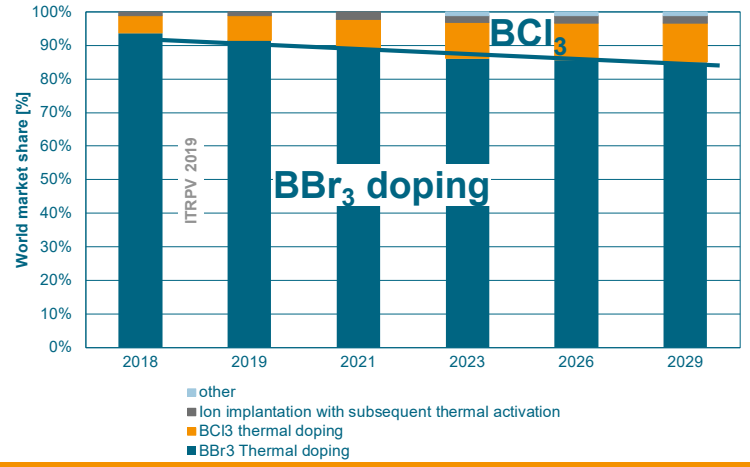
B-doping: 2018: 90 Ω/□ → 2029 120 Ω/□

Trend: doping processes

→ P-doping: selective emitter will gain



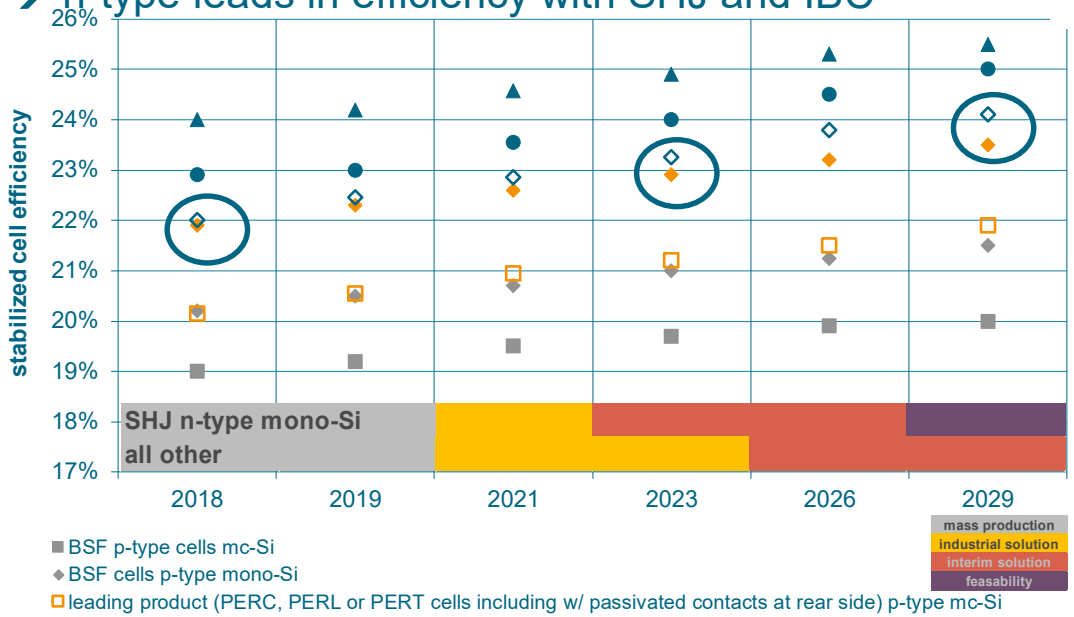
→ B-doping: BBr_3 is mainstream



Cell: Product – cell efficiencies in mass production

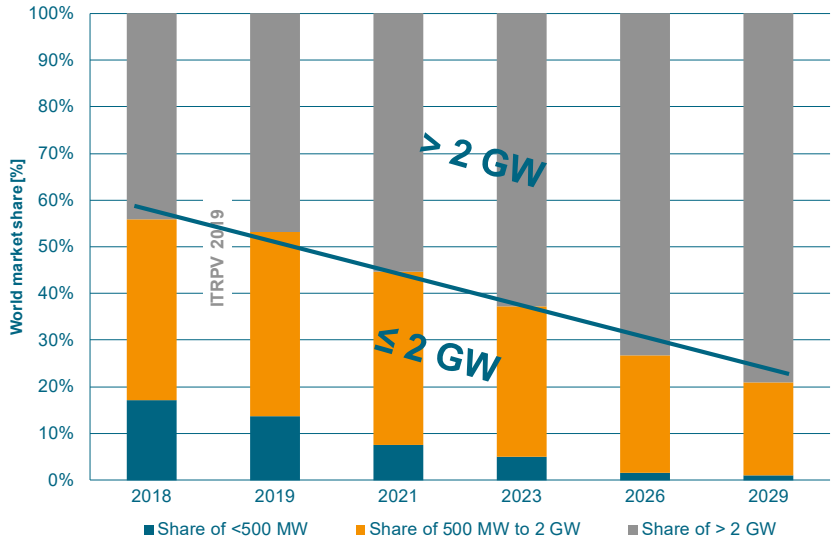
Trend: cell efficiency

→ n-type leads in efficiency with SHJ and IBC



Trend: Cell fab size

→ 2GW will be min. Fab size



→ Manufacturing challenge: Ramping up larger fabs – faster!

	2018	2023	2029
mc-Si PERC:	20.2%	21.0%	22.0%
p-mono PERC:	22.0	23.0	23.5%
n-mono PERX:	22.0%	23.2%	24.0% →passivated contacts
SHJ:	23.0%	24.0%	25.0%

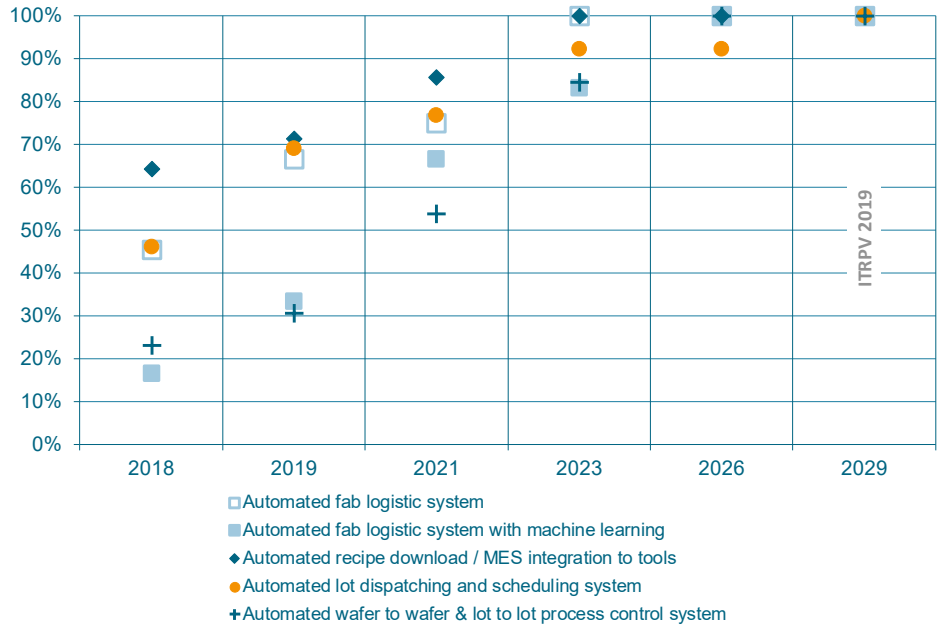
Cell manufacturing - machine throughput and MES

Trend: Machine Learning / automatic transport

→ high penetration is expectations for future fabs

Automatic transportation w/ machine learning

MES w/ automatic recipe downloads

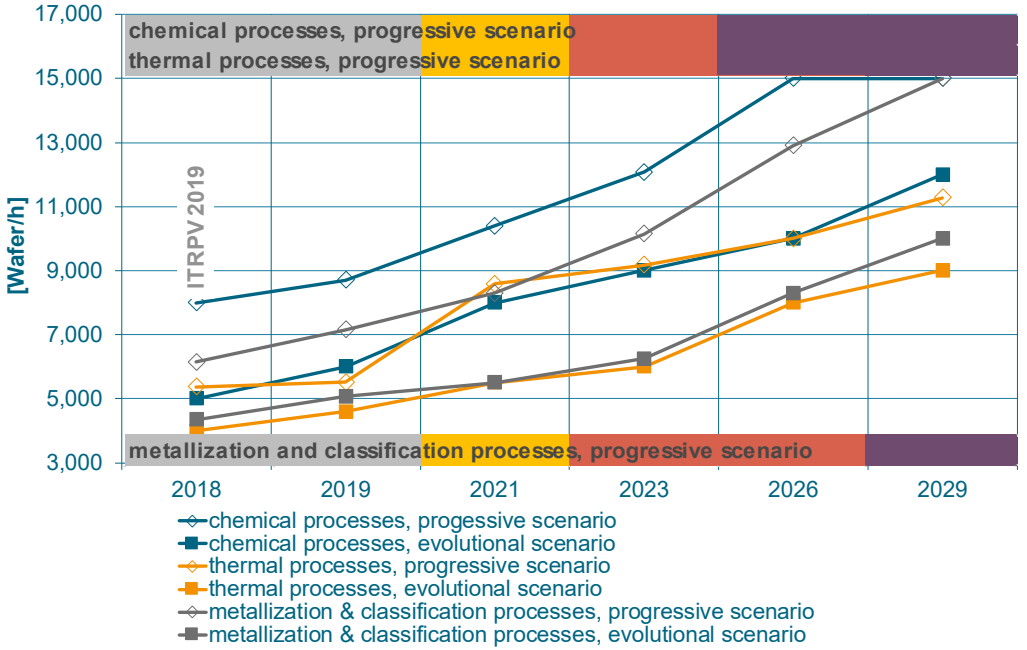


Trend: throughput of cell tools

→ significant increase for new tools

→ fast implementation possible (yellow marking)

→ going beyond 2021 values requires development



Module: Product – CTM and module power in mass production

Trend: CTM

→ ≈1% difference mc- / mono Si

→ ≈2% CTM boost for half cell modules

Efficiency will become more important value for modules →

Trend: Module efficiency will increase

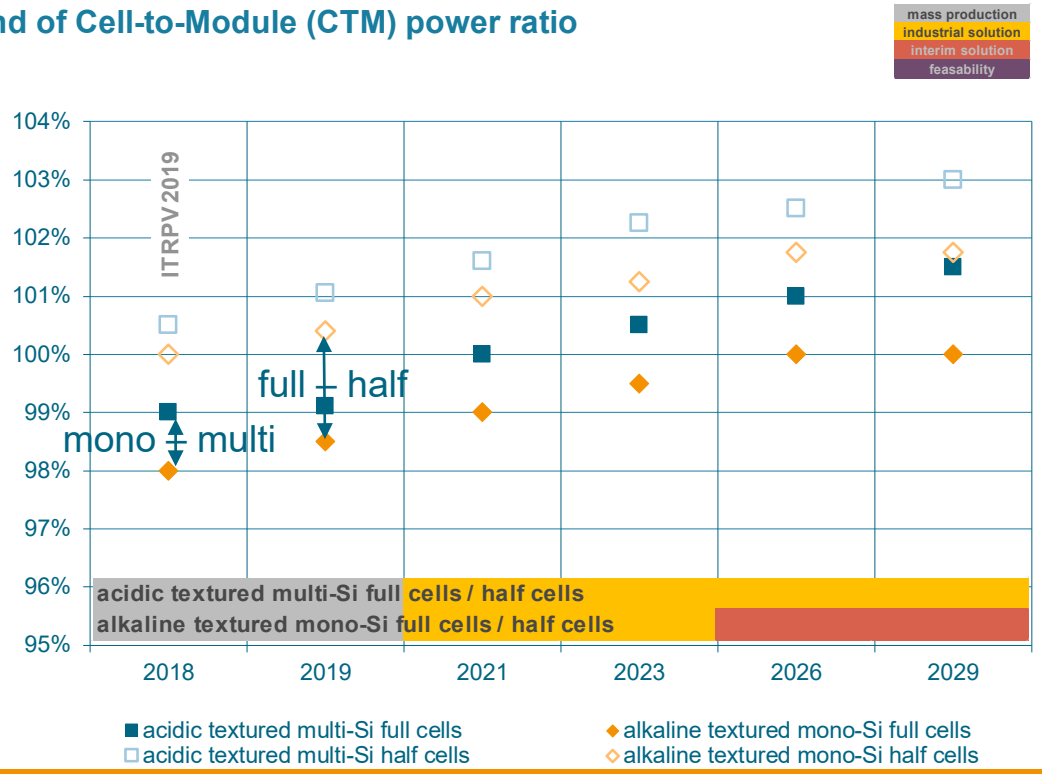
2019 → PERC p/n mono ≈320/320 Wp **≈19.4%**

2026 → PERC p/n mono ≈340/350 Wp **≈ 20.4% / 20.9%**

➔ larger formats enable higher power

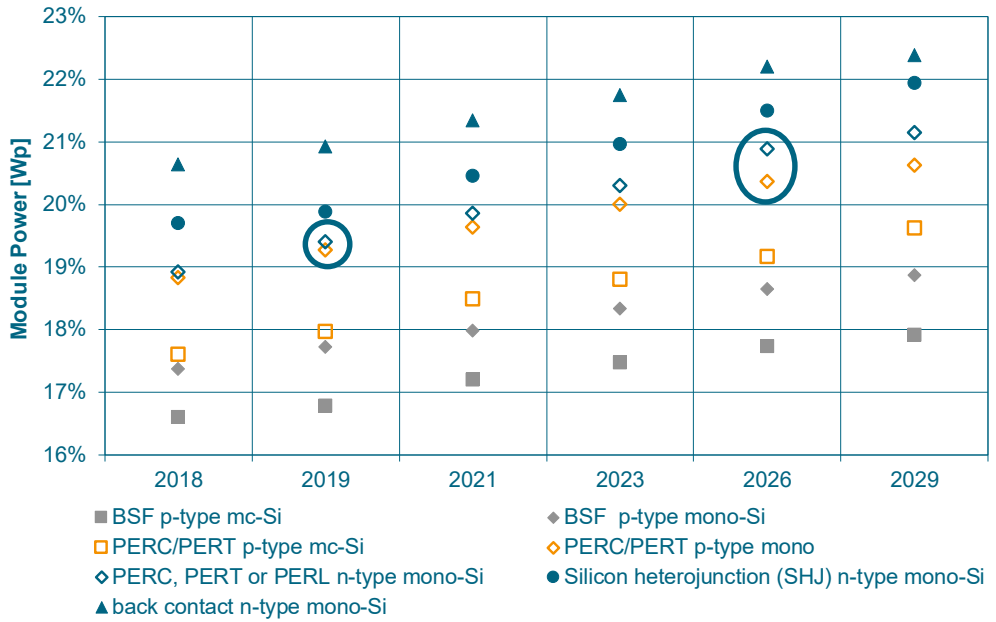
M2:M4:M6 ≈ 1 : 1.06 : 1.12 area/power

Trend of Cell-to-Module (CTM) power ratio



Module Power for 60-cell (156.75x156.75mm²) 1.67m² module

(include highest stabilized power - measured frontside STC)

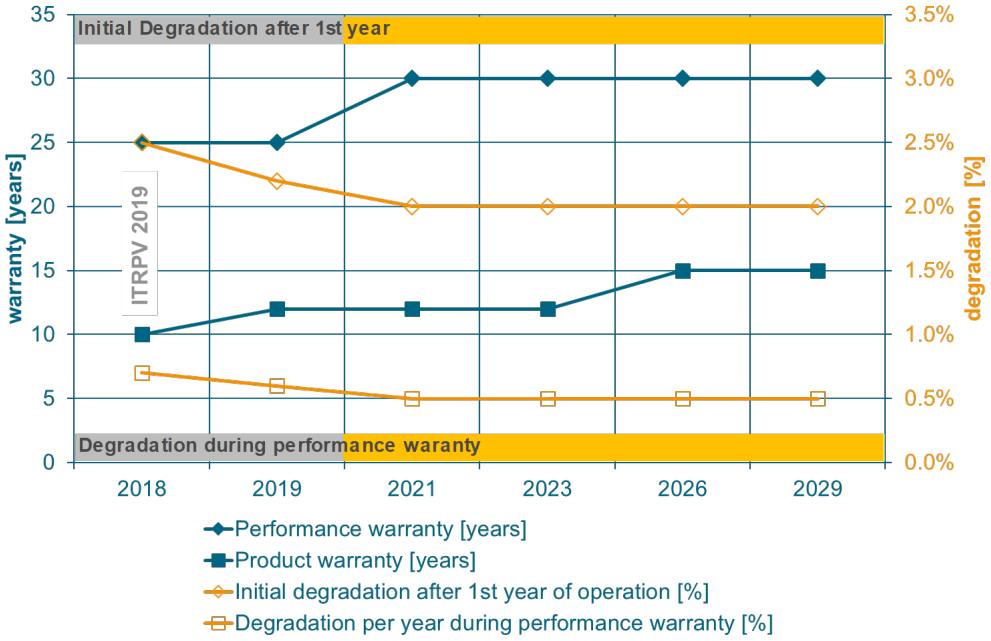


Module: Product – product warranty

Trend: product warranty

→ 1st year warranty: 2%
→ performance warranty: 0.5%/y
→ product warranty: 15y in 2021

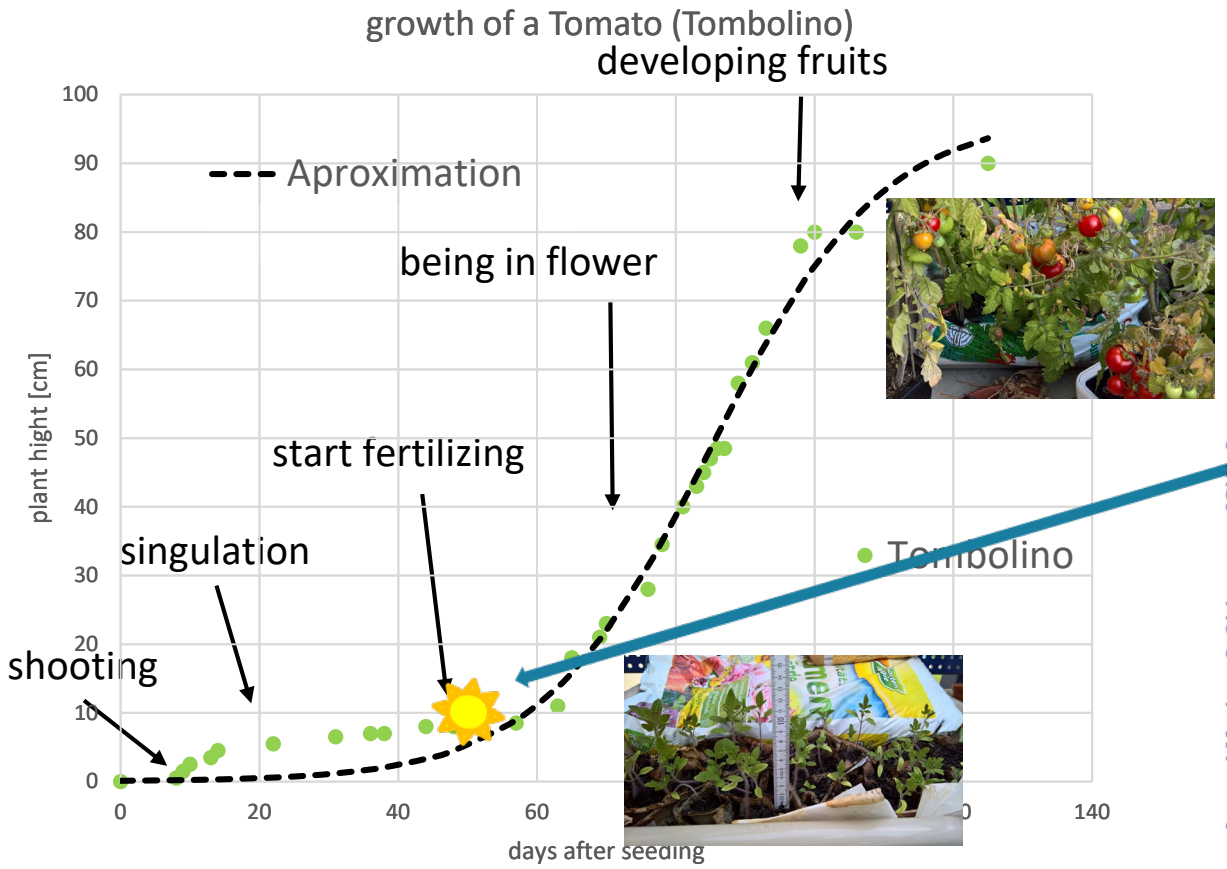
} will be reached fast as indicated by the yellow marking



PV status – seen in the perspective of natural growth cycle

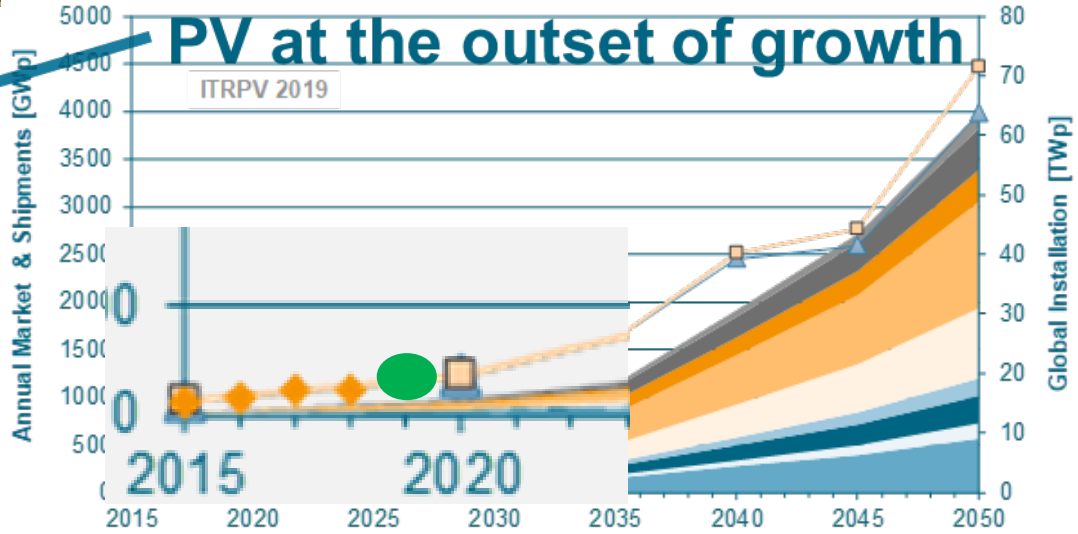
PV experiment: Investigation of the growth of a Tomato plant (German product, “Tombolino” *)
→ **look at PV growth:** stacked logistic growth curves for different world regions

$$N(t) = \frac{G}{1 + e^{k(c-t)}}$$



Parameter set: G = 1.12 m k =0.07; c = 67d

→ Example: mixed scenario 10th edition
installation: 63 TWp/ 104 PWh (electricity + primery energy)
shipments: 70 4.5 TWp/year in 2050



* Plants grown on my balcony in Thalheim April – August 2018

Outlook - PV today and in future

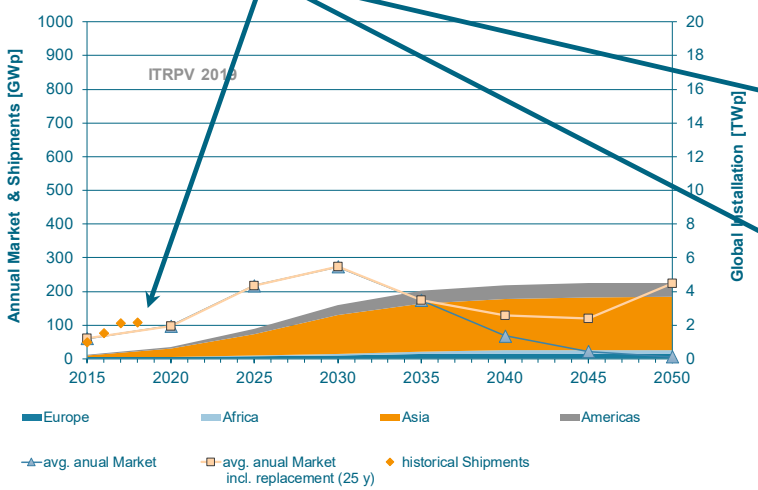
Different calculated scenarios in 10th edition:

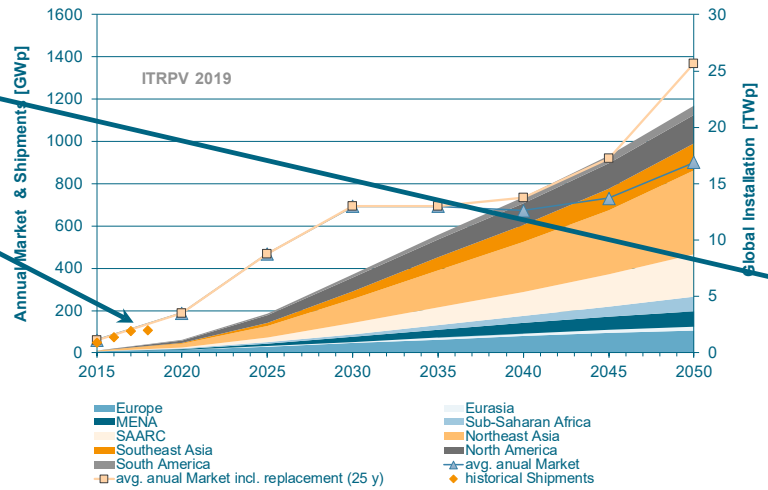
IEA
low: 4.5 TWp/ 7 PWh (16% global electricity)
market peak:300+GWp / 2030

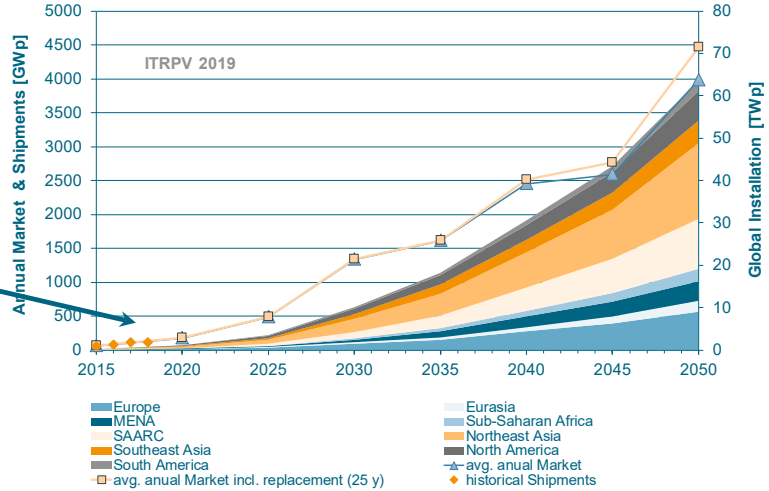
Breyer ("Electricity")
high: 22 TWp/ 38 PWh (69% global electricity)
market peak: 1,400+GWp /2050

Breyer ("Broad electrification")
mix: 63 TWp/ 104PWh (69% global energy)
market peak:4,500+ GW/ 2050

→ Shipments 2018 were close to approaches!







ITRPV finding:
- PV learning continues and progresses but market will remain volatile
→ X times 100GW annual PV markets are ahead, and can be served based on todays PV technologies
→ Corresponds to equipment markets of 20…400GW/a

Summary

- **Silicon based PV is key for a future zero greenhouse gas emission economy**

- PV market will further increase (turbulently) by

  → further reduction of LCoE
  → diversifying (regarding technology, products, and application)
  → remaining extremely cost sensitive
  → increasing production capacity while further employing economy of scale

- **ITRPV will describe path to stay competitive**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Thank you

Thank you

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