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ITRPV | International Technology Roadmap for Photovoltaics

VDMA

International Technology Roadmap for Photovoltaics (ITRPV) 8th edition:

Crystalline Silicon Technology – Current Status and Outlook

A. Metz, M. Fischer, J. Trube

PV Manufacturing in Europe Conference
Brussels, May 19th 2017

Outline

1. ITRPV Introduction

2. PV Learning Curve and Cost Considerations

3. ITRPV – Results 2016
   - Wafer - Materials, Processes, Products
   - Cell - Materials, Processes, Products
   - Module - Materials, Processes, Products
   - Systems

4. Summary and Outlook

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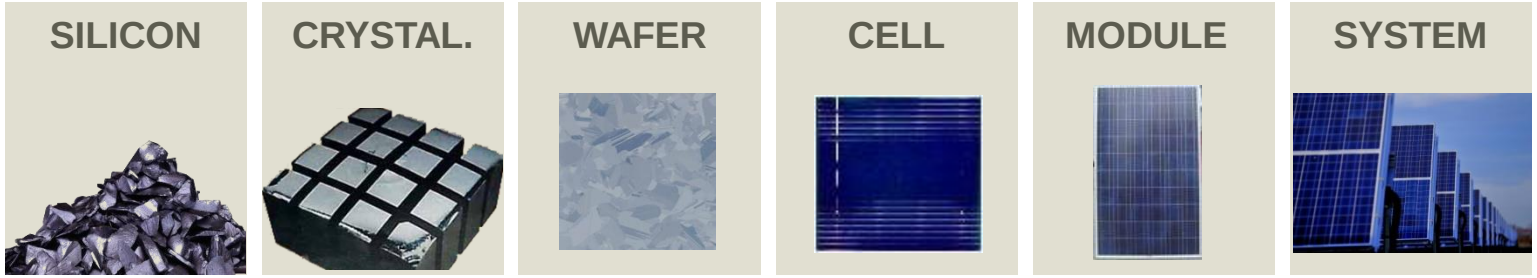
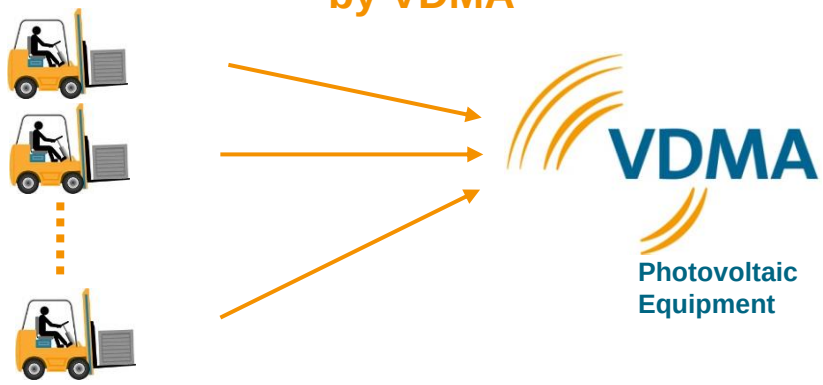
ITRPV – Methodology

Working group today includes 40 contributors from Asia, Europe, and US



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



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

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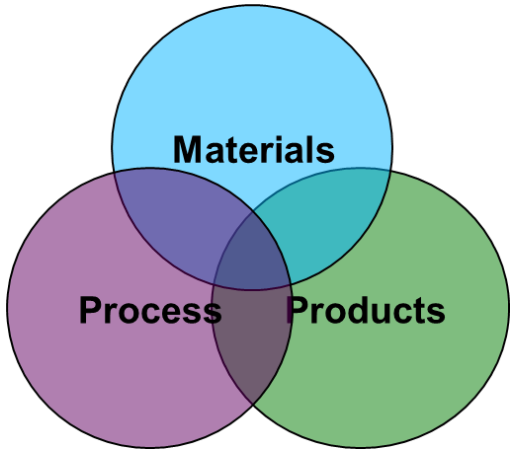
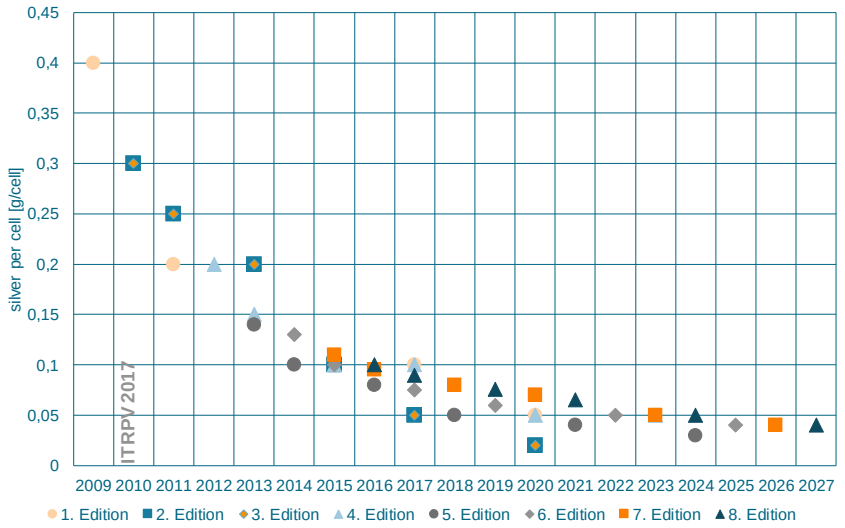


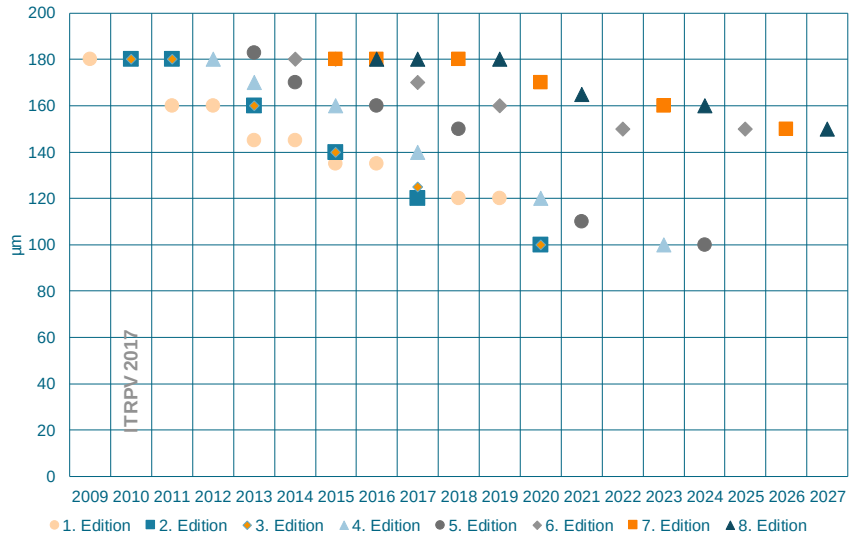
Parameters in main areas are discussed → Diagrams of median values

ITRPV 8th Edition 2017 – some statistics

Silver amount per cell



Wafer thickness (multi)



Edition	8th	7th
Contributors	40	33
Figures	60	50

Prediction quality since 2009:

Silver consumption trend → well predicted and realized
(Silver availability depends on **world market**)

Wafer thickness trend → bad predicted and no progress
(Poly-Si price depends on **PV market** development)

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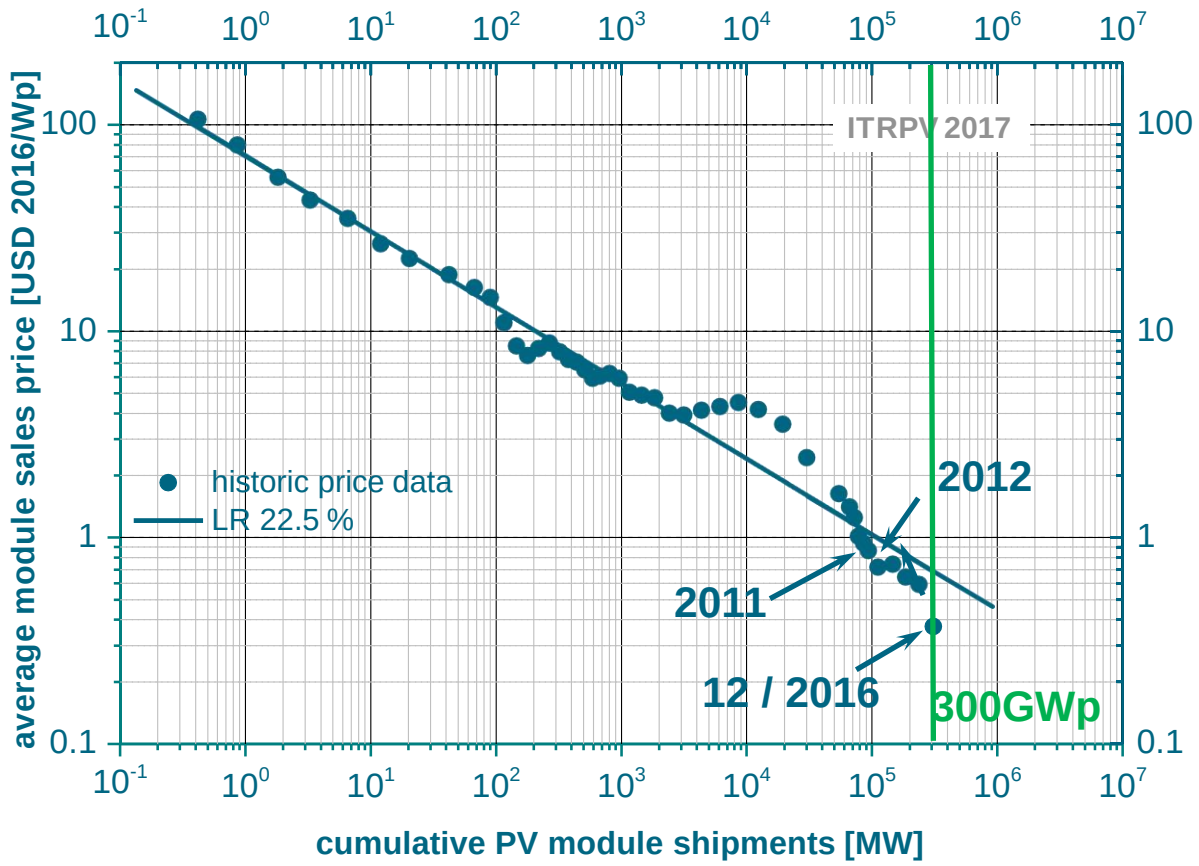
PV learning Curve



Shipments /avg. price at years end:

2016: 75 GWp / 0.37 US$/Wp

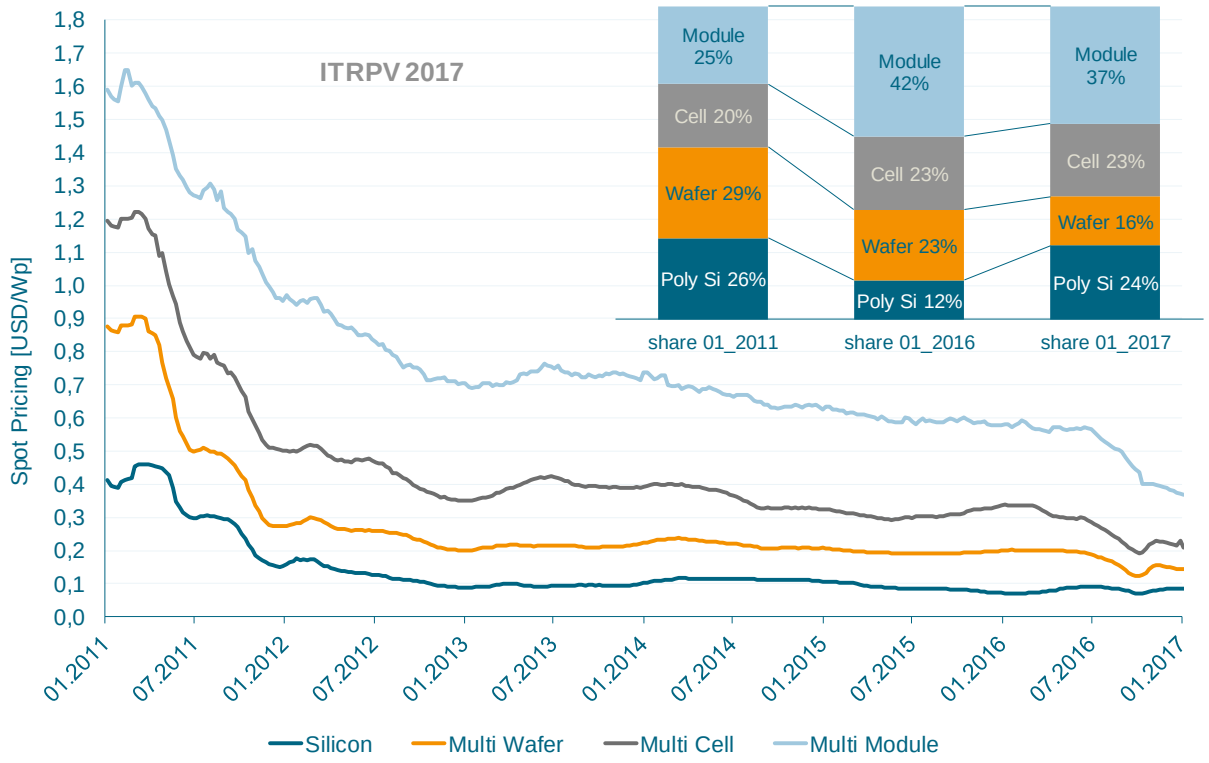
o/a shipment: ≈ 308 GWp
o/a installation: ≈ 300 GWp

300 GWp landmark was passed!

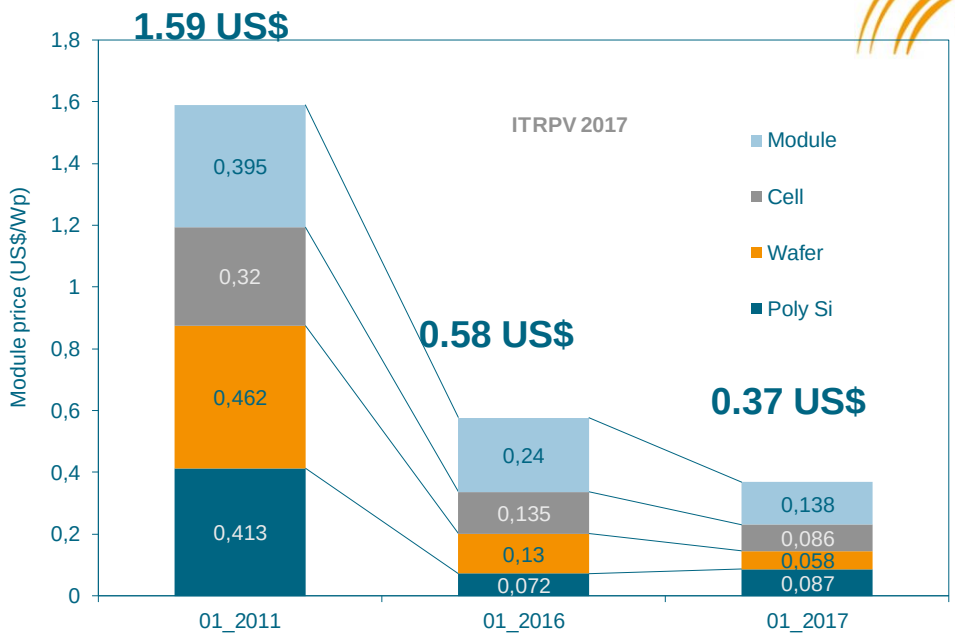
LR 21.5% (1976 …. 2016)

dramatic price drop due to market situation
→ Comparable to 2011/2012, but faster

Price considerations



Module price break down [US$/Wp]



→ reduction 01/2011 → 01/2016: ≈ 64 %
→ reduction 01/2016 → 01/2017: ≈ 36 %
(reduction 01/2011→ 01/2012: ≈ 40 %)

Dramatic price drop during 2nd half of 2016

→ **Market driven drop**

→ **Poly-Si share increased again**

→ **High pressure on module manufacturers**

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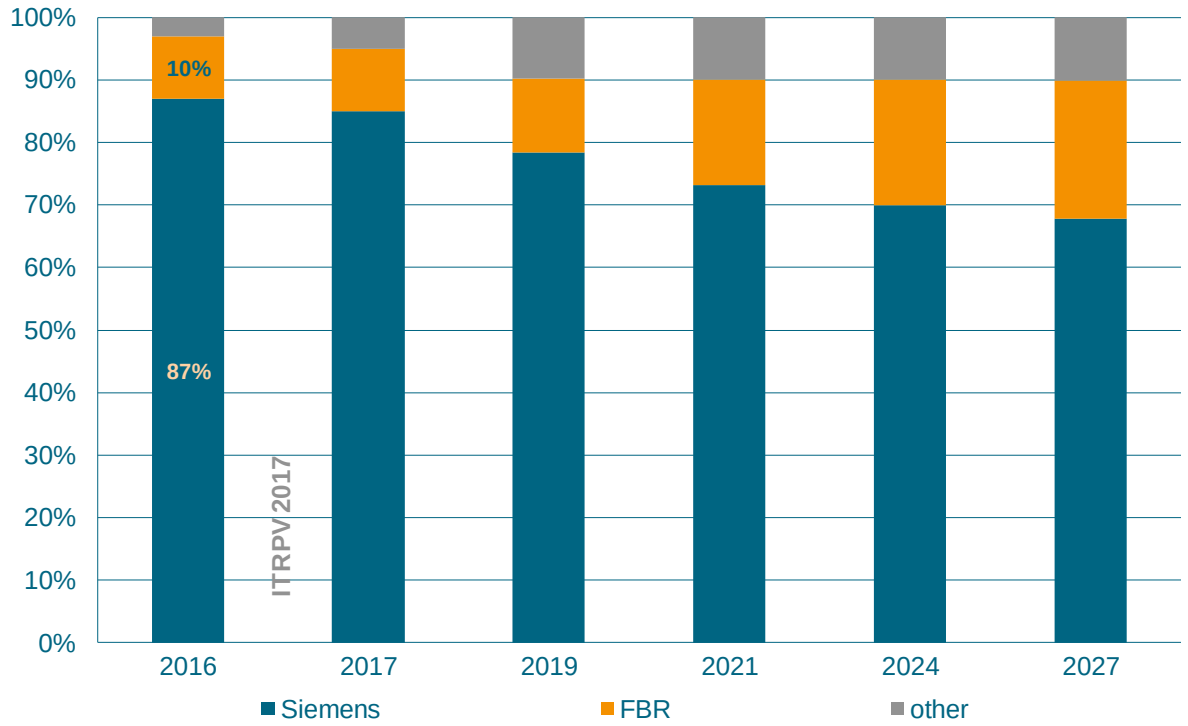
Silicon – Materials: Poly Si Feedstock Technology

Trend: Share of poly-Si feedstock technology

Silicon feedstock technology

World market share [%]



Poly Si price trend:

E 2012: 20 US$/kg

02/ 2016: ≈14 US$/kg

02/ 2017: ≈16 US$/kg

→ oversupply situation of 2016 relieved

→ Siemens process will remain mainstream
FBR shows potential for cost reduction

→ **FBR share will be increased moderately w/ new capacity**
(2016 values in line w/ IHS Markit)

Other technologies (umg, epi growth, ..)
→ Not yet mature but available

Wafer – Processes: wafering technology (1)

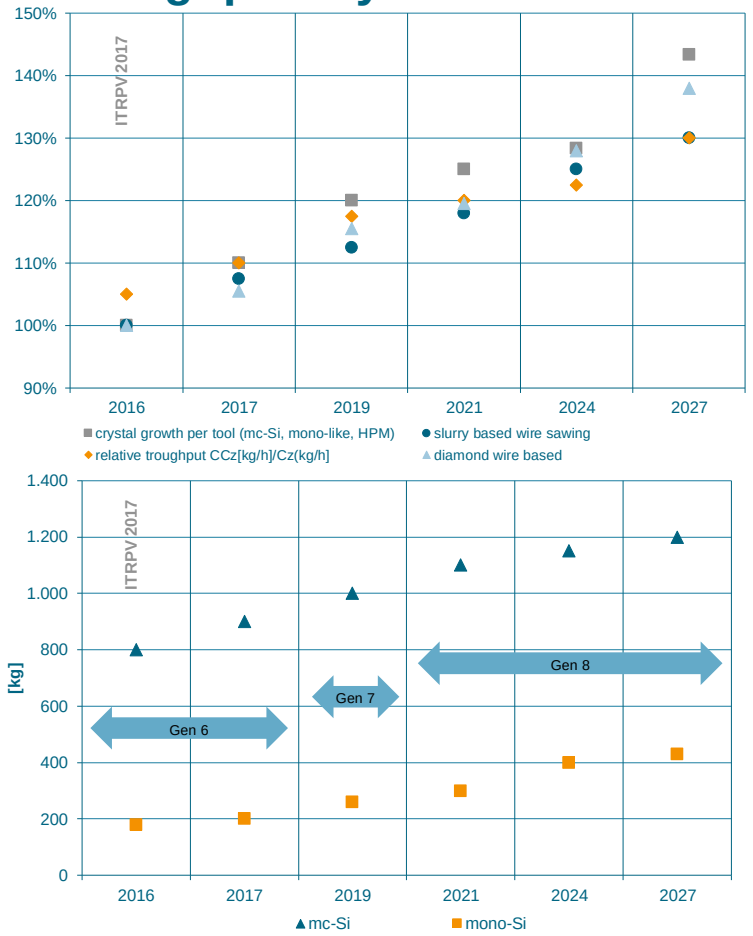
Trend: Kerf loss / TTV

diamond wire sawing advantage:

→ enable faster kerf reduction

No big change in thickness variation is expected

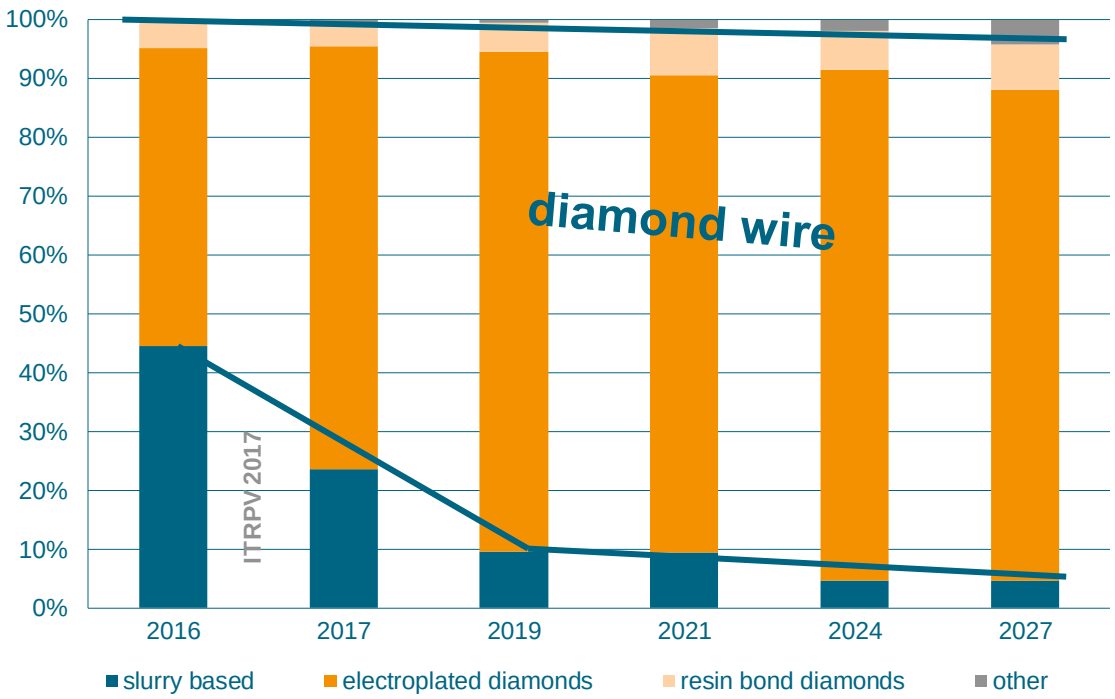
Trend: throughput crystallization/ wafering



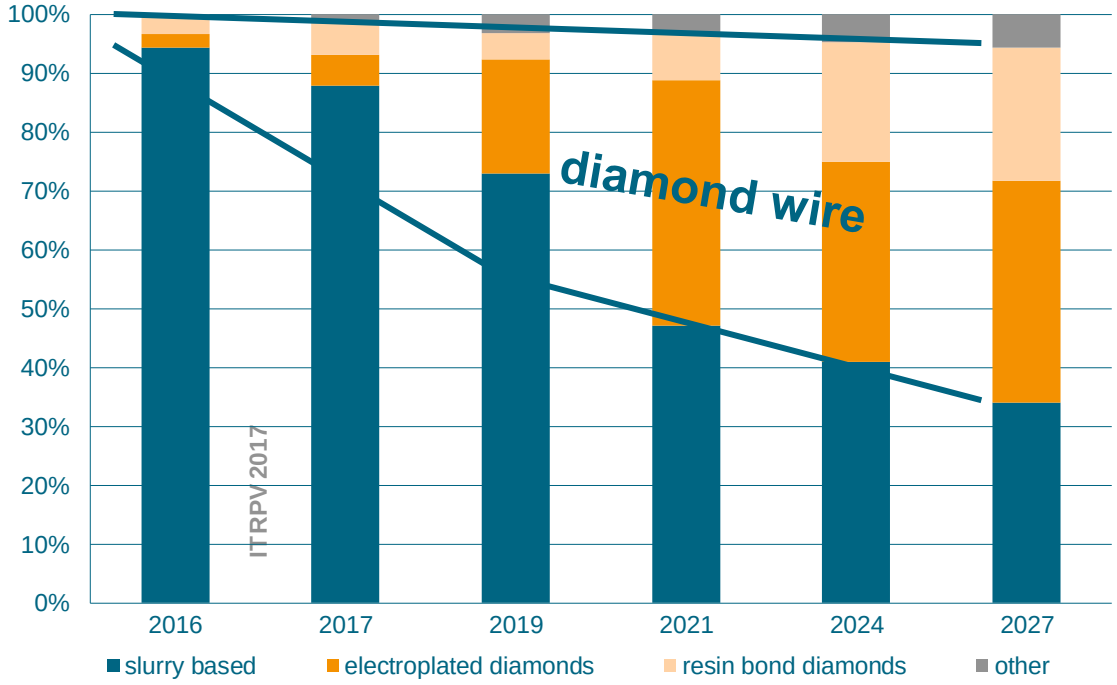
→ Throughput increase in crystallization/wafering will continue

Wafer – Processes: wafering technology (2)

For mono-Si



For mc-Si

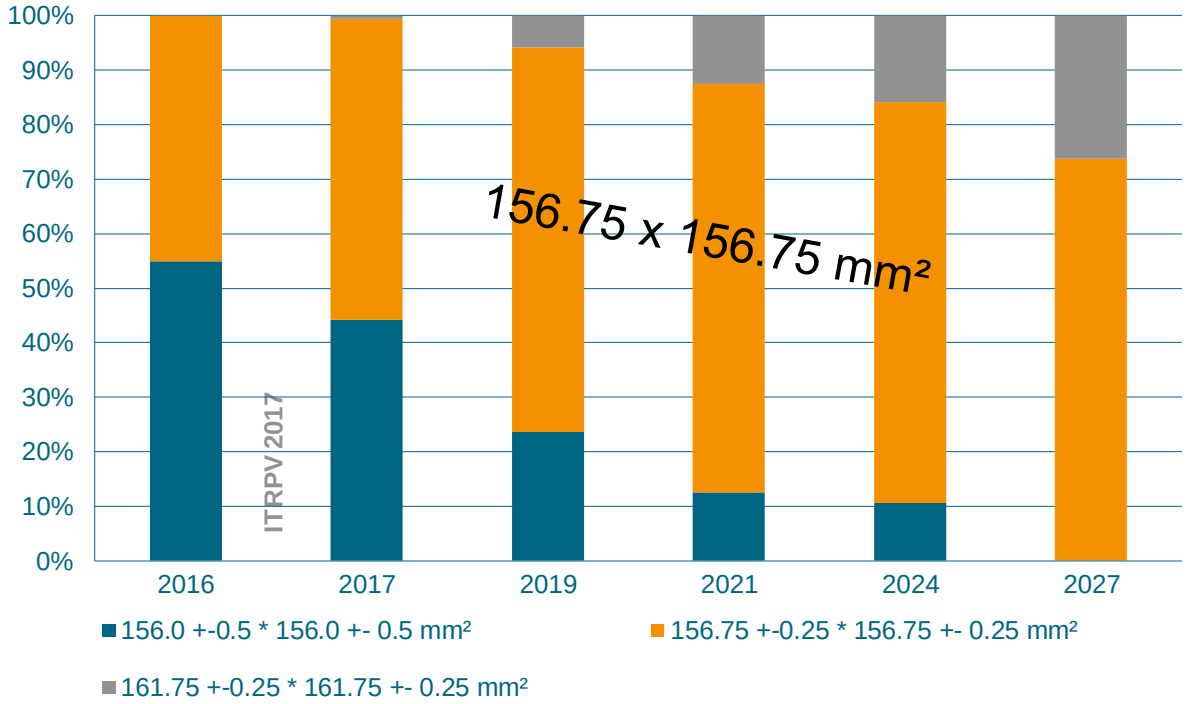


diamond wire wafering now mainstream for mono-Si
→ Throughut 2x – 3x faster than slurry based

For mc-Si change to diamond wire is ongoing
→ **main challenge: texturing**

Wafer – market share of wafer dimensions (new)

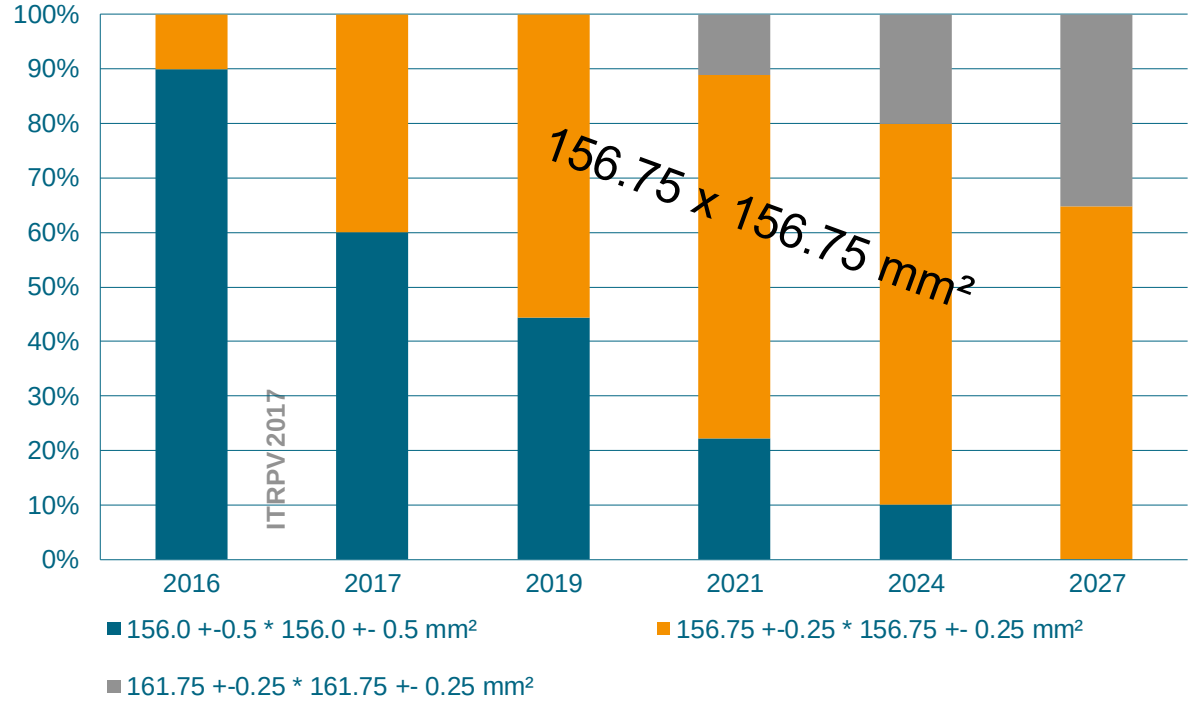
Trend: mono-Si



Fast switch to new format:

→ **New mainstream: 156.75 x 156.75 mm²**
→ **Larger formats are upcoming**

Trend: mc-Si

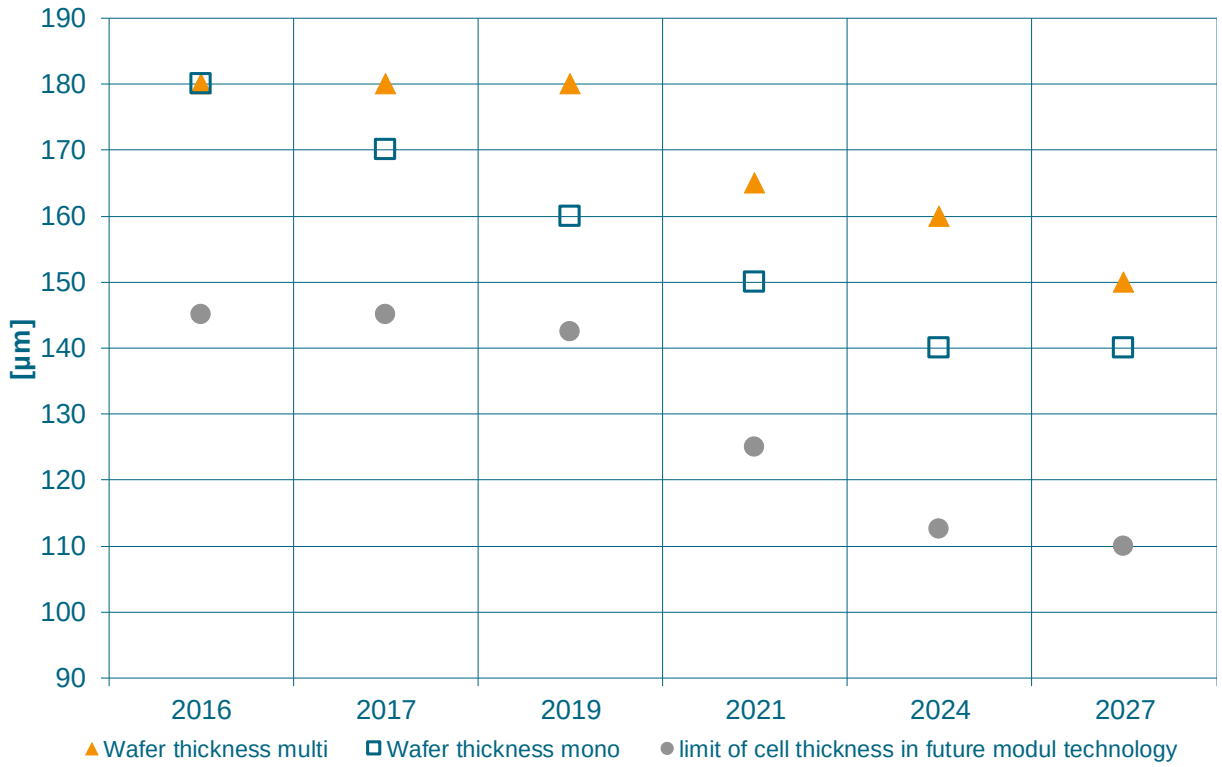


Transition to new format in 2017

→ Expected new mainstream: 156.75 x 156.75 mm²
→ Larger formats may occur after 2020

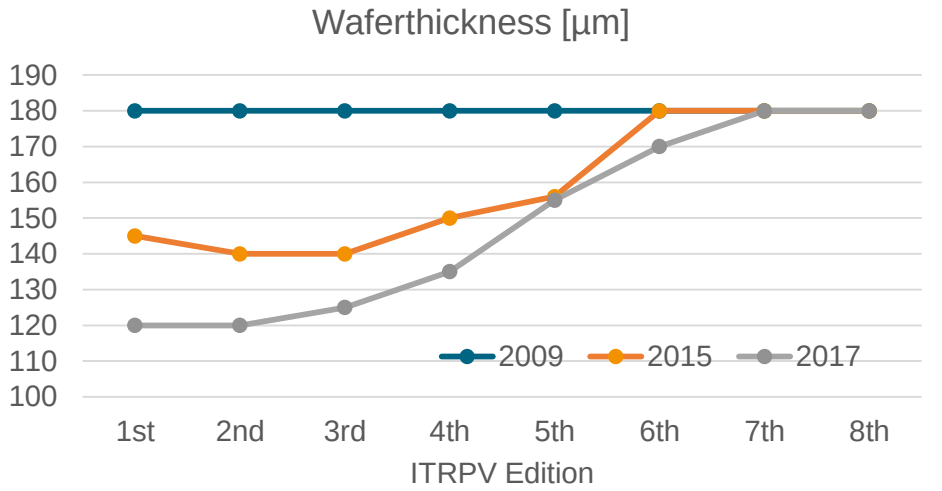
Wafer – Product: thickness trend

Trend: wafer thickness for mc-Si and mon Si wafers



Mono wafer: thickness reduction starts

- Still no progress in mc-Si thickness reduction



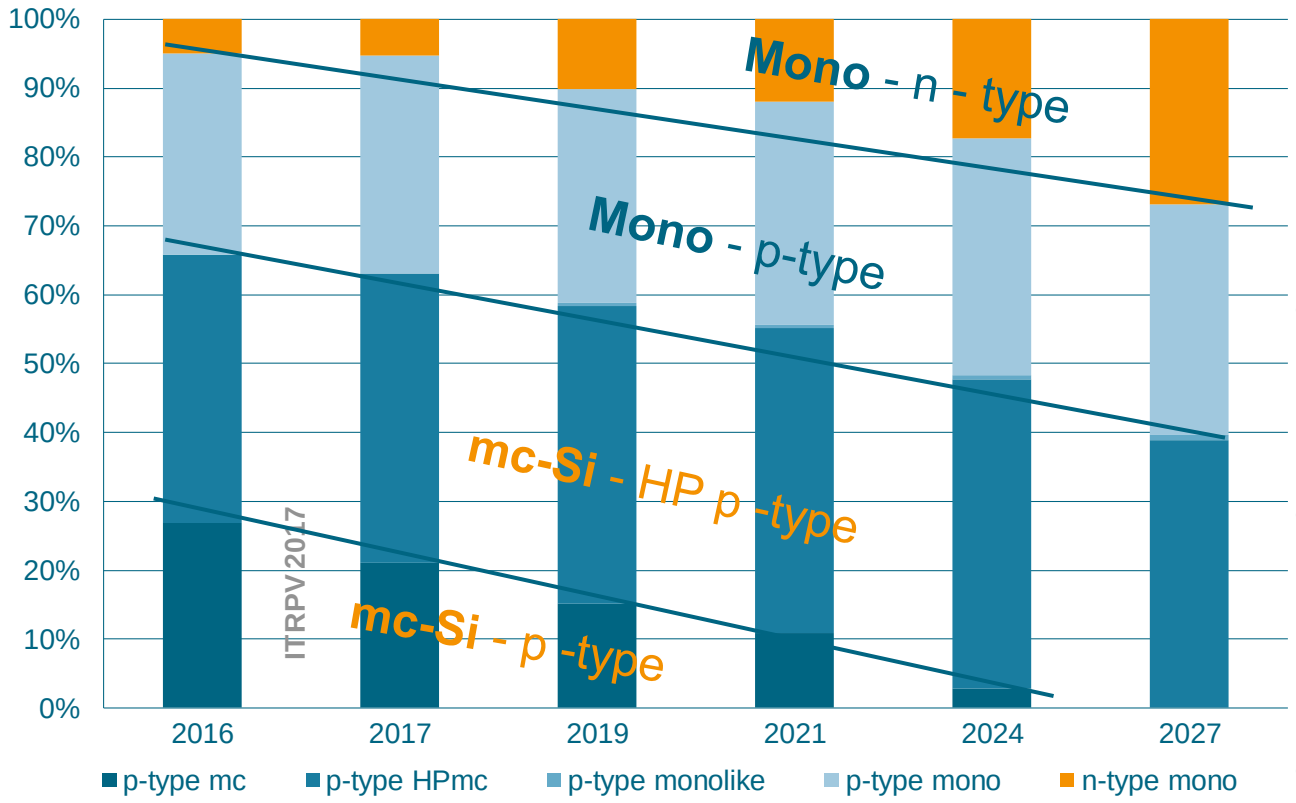
→ 180µm = preferred thickness since 2009

- Thickness reduction is expected to start for Mono
  → cost reduction potential
  → diamond wire will support

New module technologies enable further thickness reduction

Wafer – Product: market share of material types

Trend: share of c-Si material types



→ **Casted material is still dominating** today with >60%

→ **Mono share is expected to increase** (driven by n-type)

casted-Si domination is not for ever:
→ Trend of last years will continue

- **Casting technology:**
  → HP mc-Si will replace standard mc-Si
  → no “come back” of mono-like expected

- **Mono technology:**
  → n-type material share will increase
  → n- + p-type market share today ≈35%
  (2016 values are in line w/ IHS Markit)

- **p-type material is expected to stay dominant**
  → mainly due to progress in stabilization

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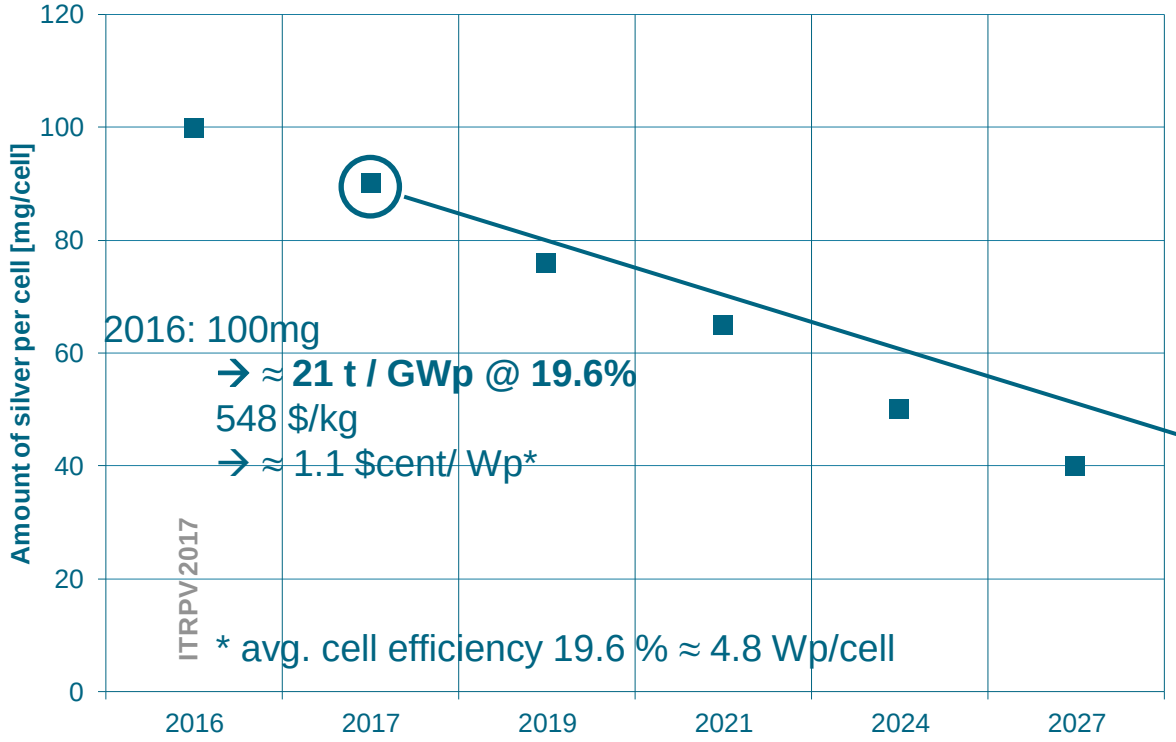
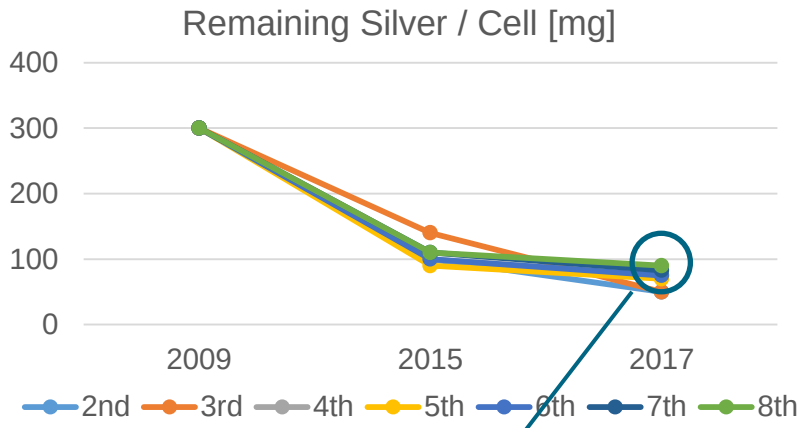
Cell – Materials: Silver (Ag) per cell



Good prediction of Ag reduction continues



2009 300 mg
2016 100 mg reached
2017 90 mg expected

→ Ag accounts in 2016 for ≈ 8% of cell conversion cost

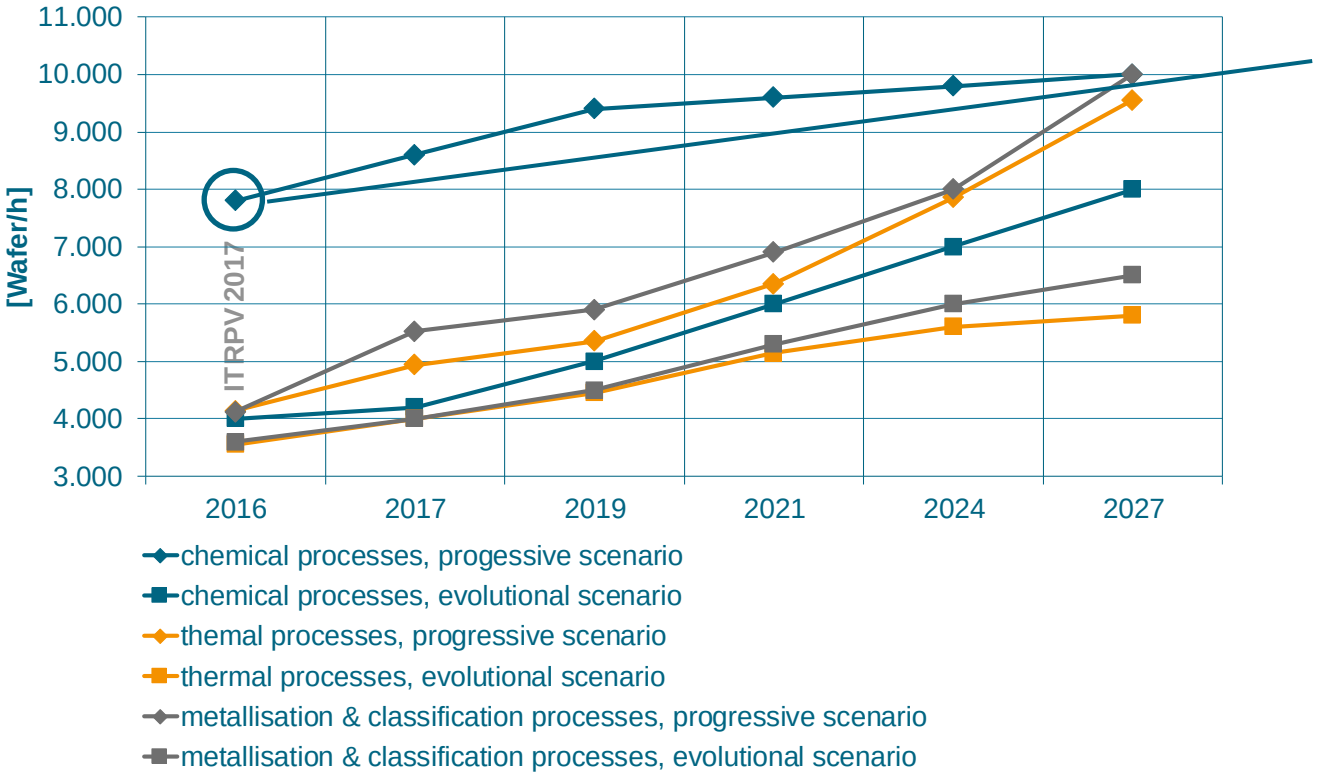
- Ag reduction is mandatory and continues
- delays substitution by Cu or other material

Ag will stay main metallization in c-Si technology

No break through for lead free pastes so far
→ Market introduction depends on performance

Cell – Processes: cell production tool throughputs

Trend: tool throughput increase + synchronization of frontend/backend



Wet benches are leading today with > 7800 wf/h
→ Throughput increase continues

Challenge: increase throughput + Improve OEE

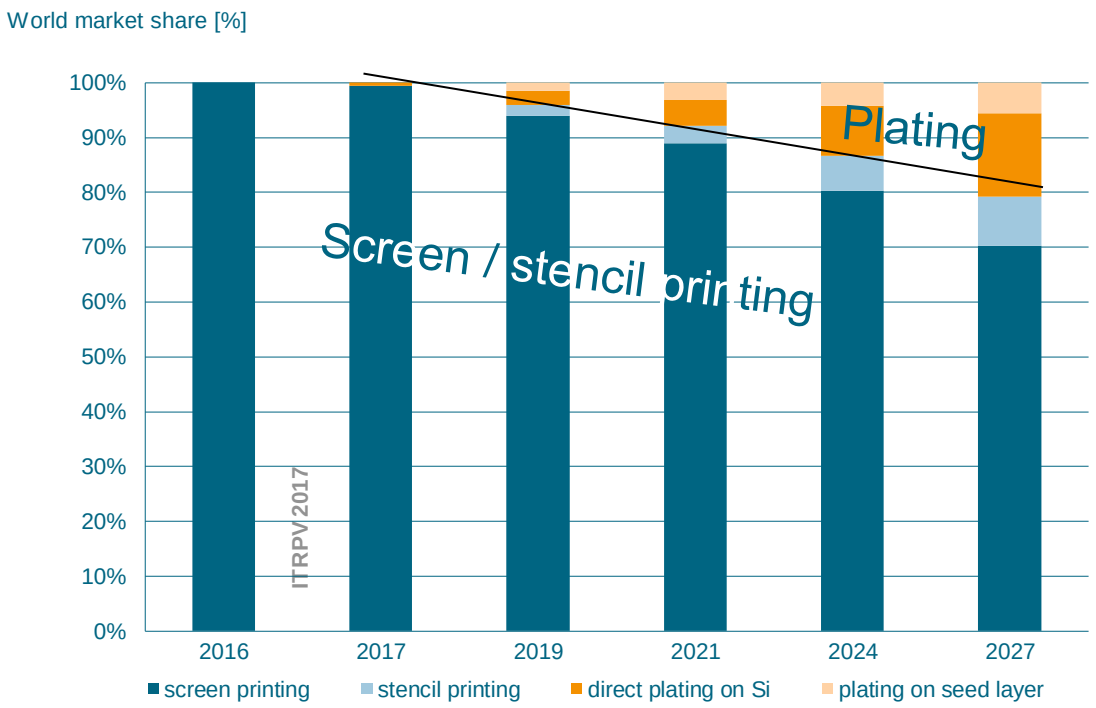
Two throughput scenarios:

Progressive = new high throughput tools

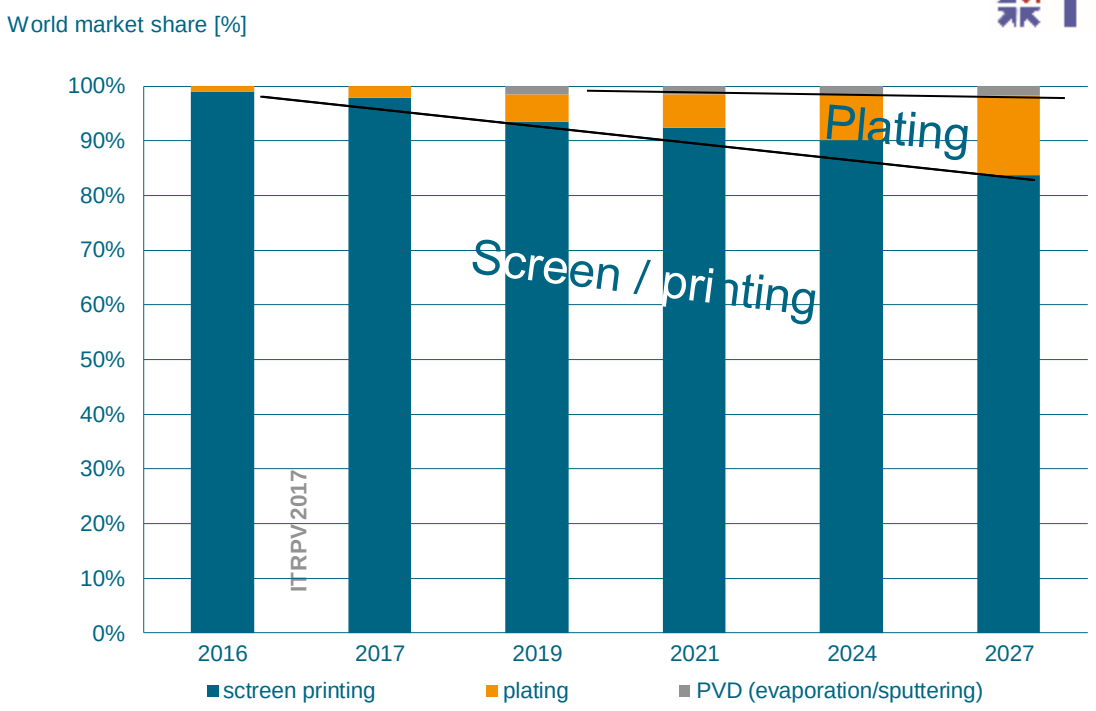
Evolutionary = continuous improvement of existing tools (debottlenecking, upgrades…)

Cell – processes: c-Si metallization technologies

Front side metallization technologies



Rear side metallization technologies



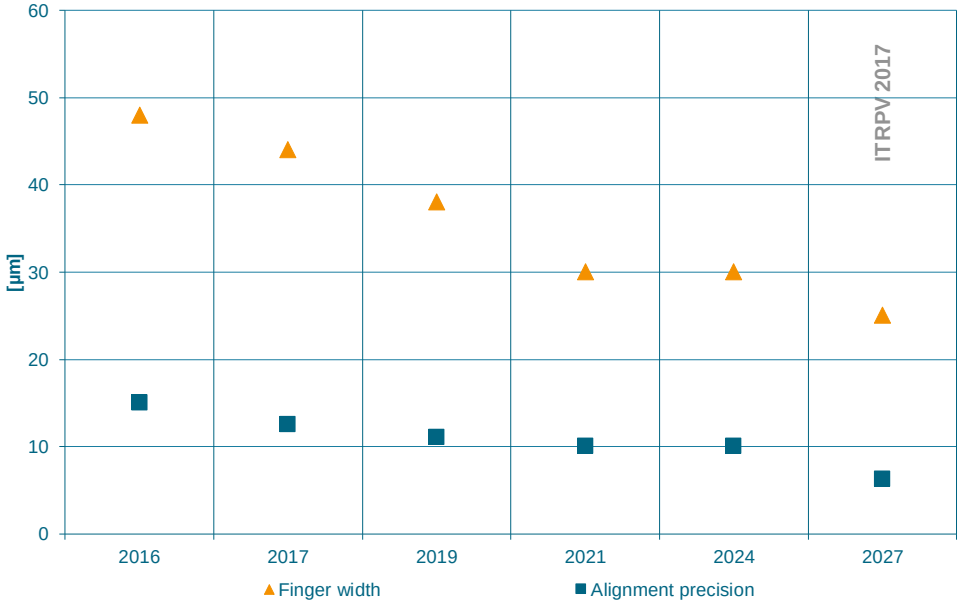
Screen printing remains main stream metallization technology

→ Plating is expected for rear and front side

→ For rear side PVD methods may appear

Cell – processes: finger width / number of bus bars / bifaciality

Trend: Finger width / alignment precision



Front side grid finger width reduction continues

2016: < 50µm reached!

→ Enables Ag reduction, requires **increase of number of busbars**

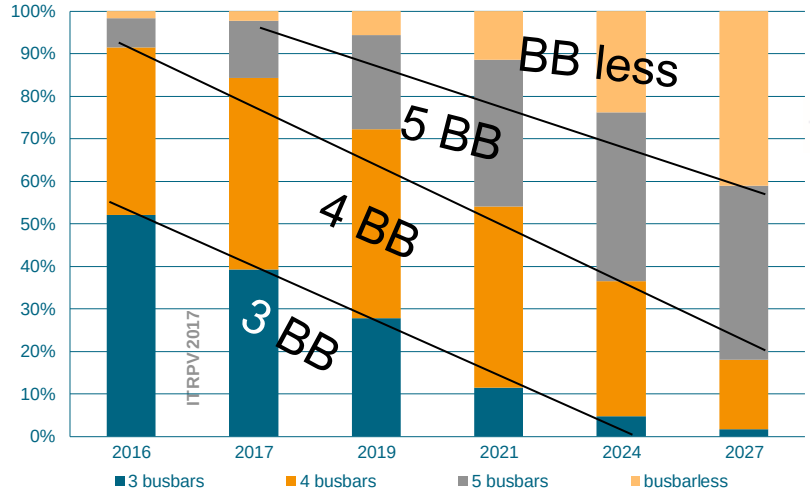
→ 4BB are mainstream – 3 BB will disappear

Alignment precision will improve to <10µm @3 sig.

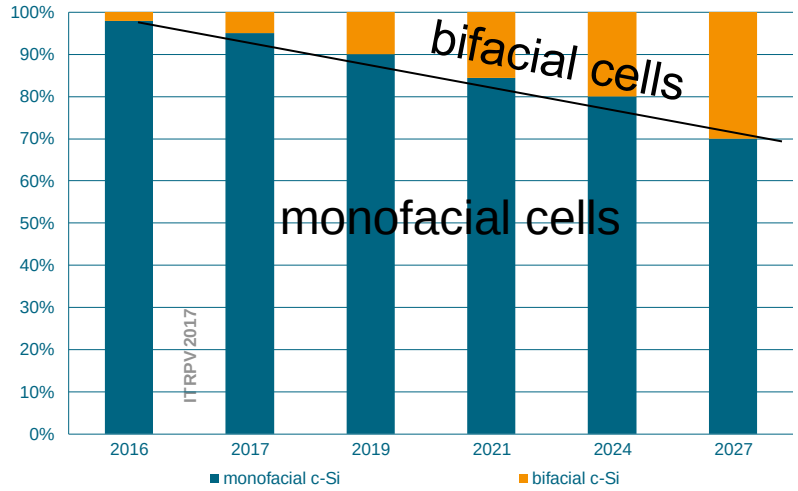
→ Selective emitters + Bifacial cells require good alignment

→ **Bifacial cells will increase market share**

Trend: number of bus bars (BB)

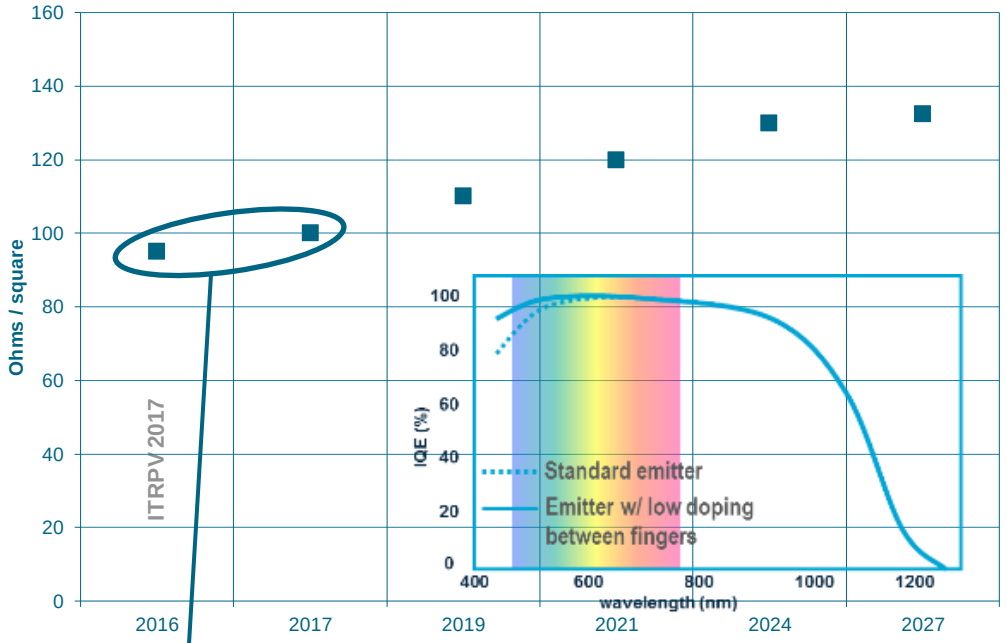


Trend: market share of bifacial cells



Cell – processes: emitter formation for low $J0_{front}$

Trend: emitter sheet resistance



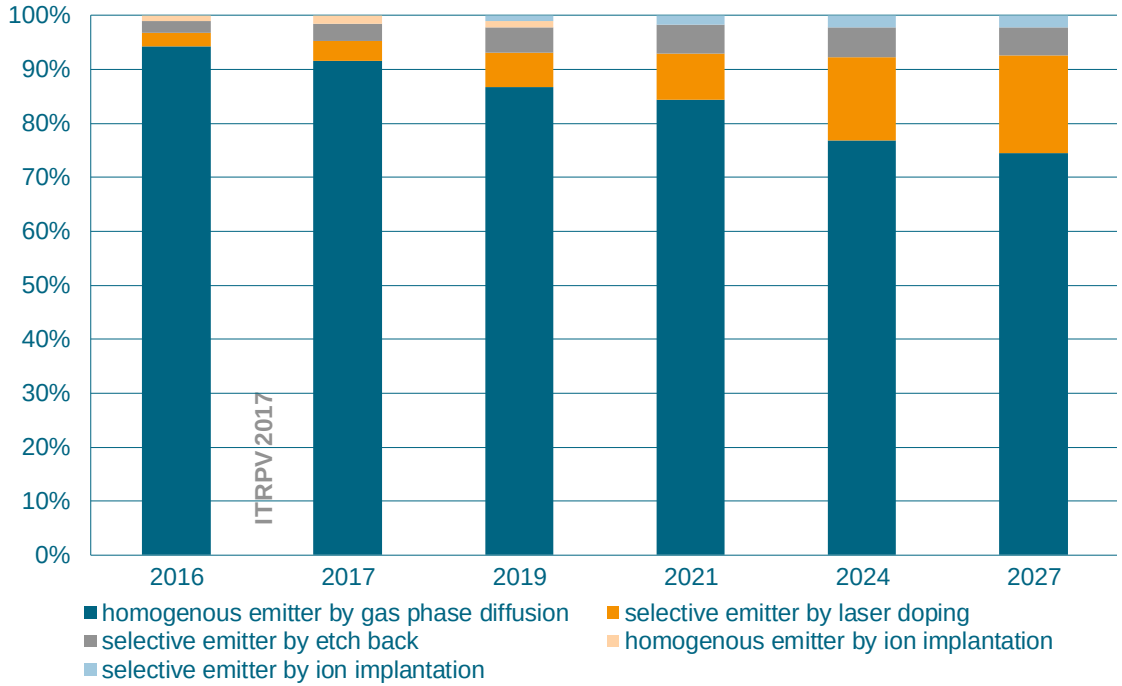
Essential parameter for J0front

→ **95…100 Ω/□** are standard today

→ Increase to 135 Ω/□ is predicted

→ **Challenge for tools and front pastes**

Trend: emitter formation technologies



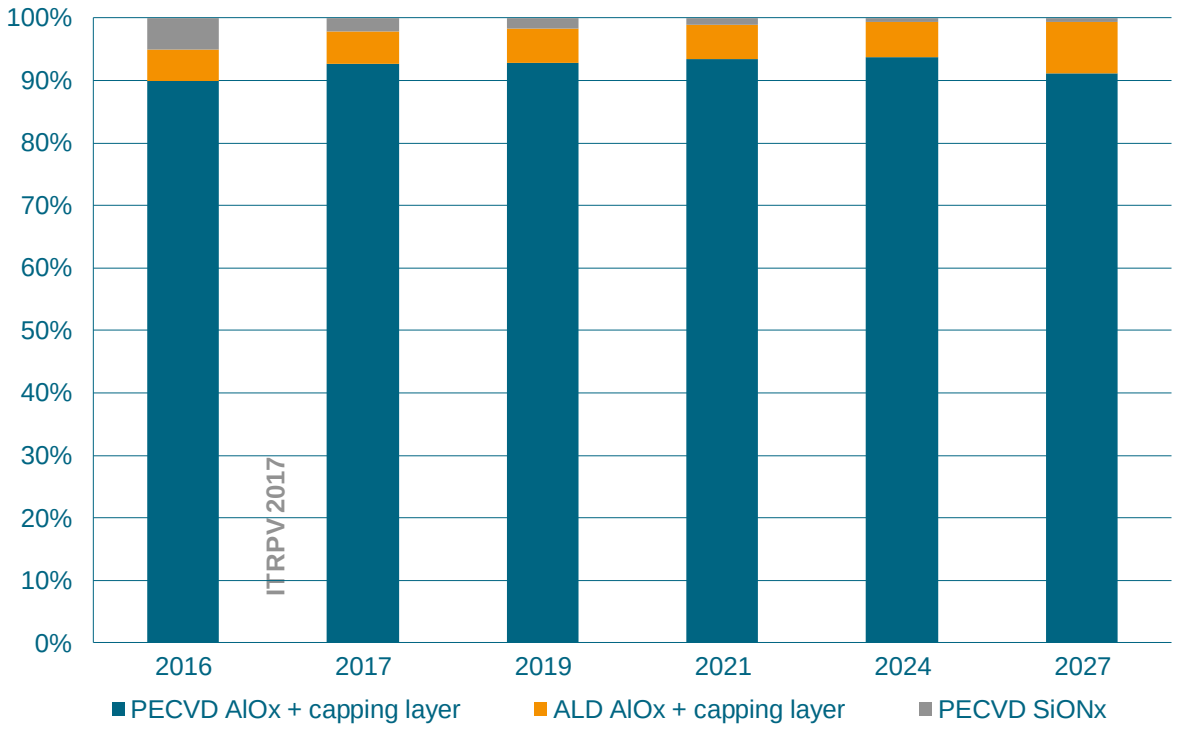
Mainstream: homogenous gas-phase diffusion

→ selective doping: etch back or laser doping

→ Ion implant stays niche

Cell – processes: technology for low $J0_{rear}$

Trend: rear side passivation technologies



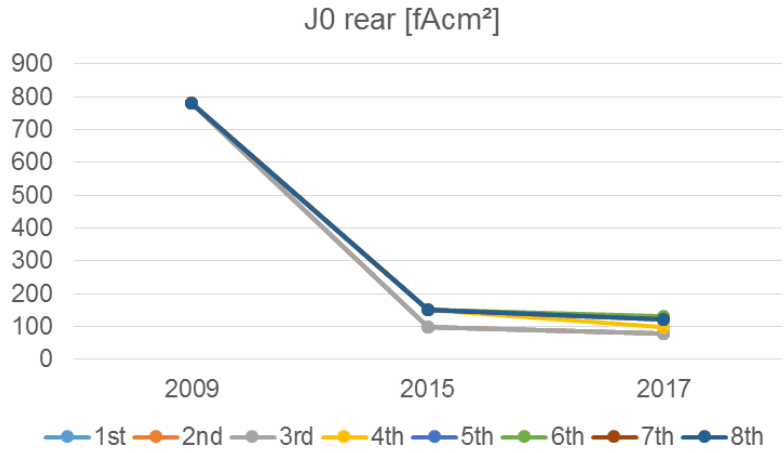
Rear side passivation is mandatory for PERC

→ **PECVD AlOx will stay mainstream**

→ ALD will hold up to 10 %

→ SiONx will disappear

ITRPV prediction for $J0_{rear}$ were good



2009 2017

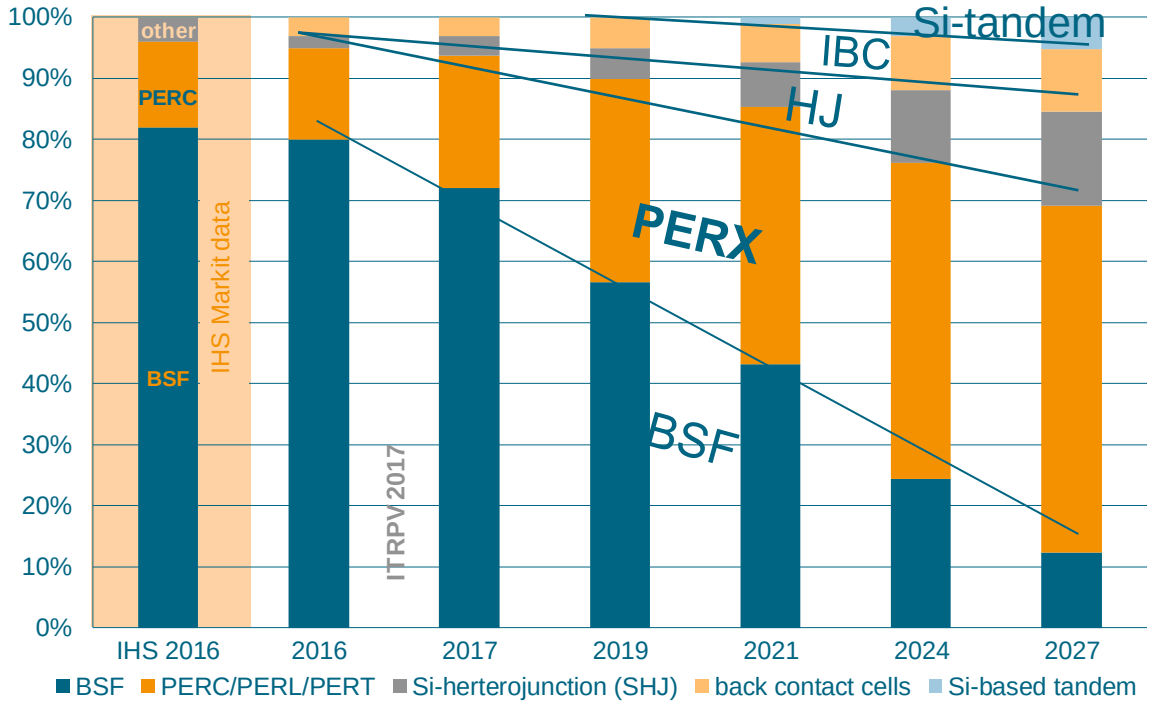
780 → 120 fA/cm²

- BSF cannot deliver required low $J0_{rear}$
- PERC takes over
- competing technologies in PERC
  → PECVD Al2O3 + capping
  → Al2O3 ALD + capping
  → PECVD SiONx/SiNy etc.

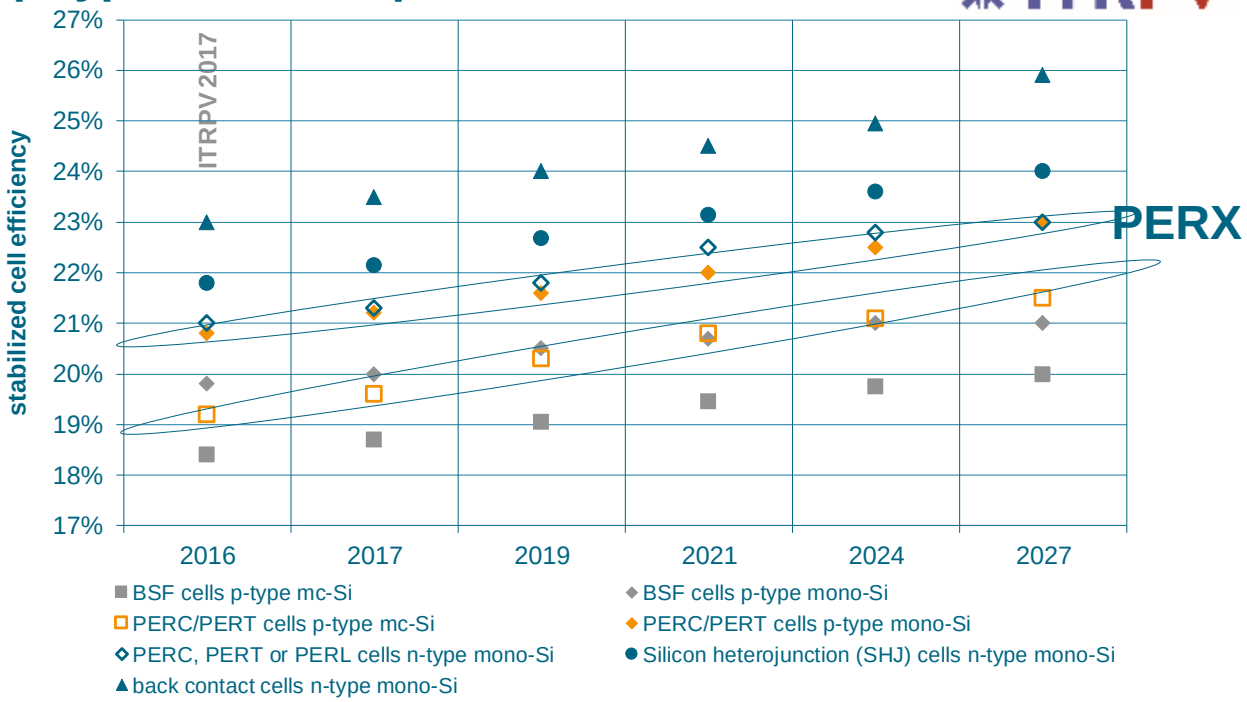
Cell – Products: cell technologies / cell efficiency trends

Trend: market share of cell concepts

2016: PERC ≈15% (in line w/ IHS Markit)



Trend: stabilized cell efficiencies;
→ p-type PERC outperforms



PERX is gaining market share (20% 2017)

→ **BSF share is shrinking**

→ Back contact + HJ: slow increasing share

→ Si tandem: under development

p-type mono PERX will reach n-type performance

mc-Si PERX is about to outperform mono BSF

→ n-type IBC + HJ for highest efficiency applications

→ **stabilized >21% p-type mono PERC is in production**

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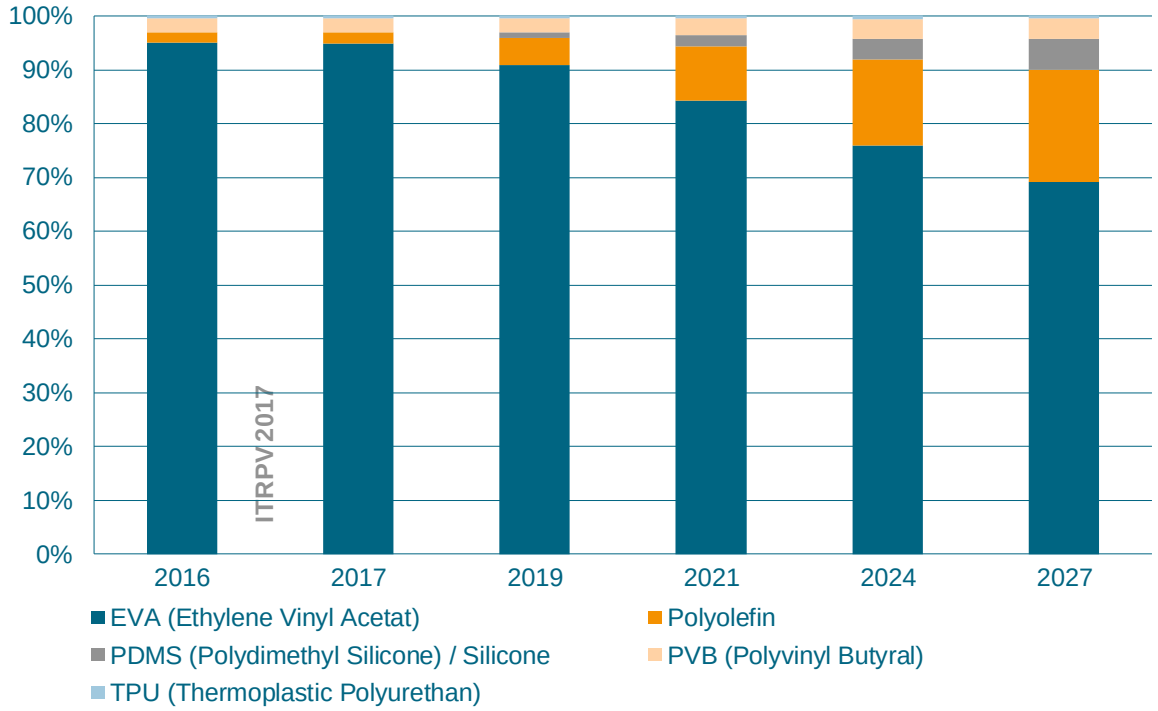
Module – Materials: foils

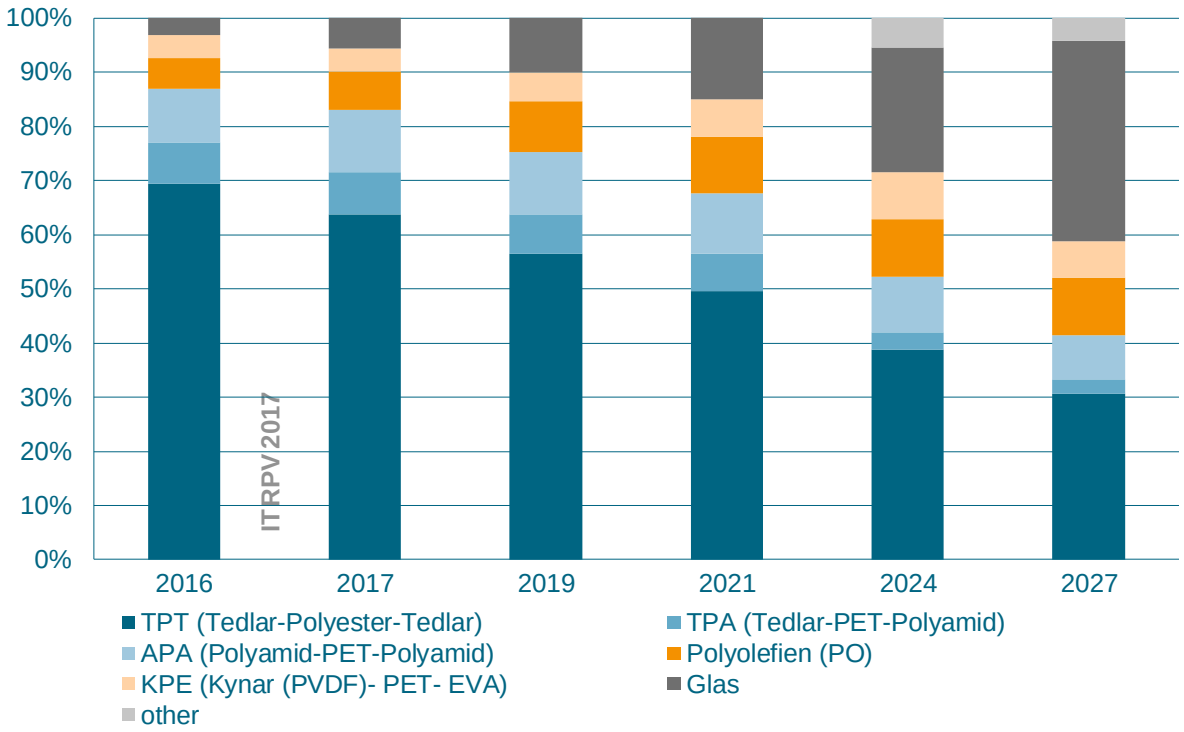
Trend: share of encapsulant materials



EVA is mainstream

Polyolefine will increase market share

Trend: share of back-sheet materials

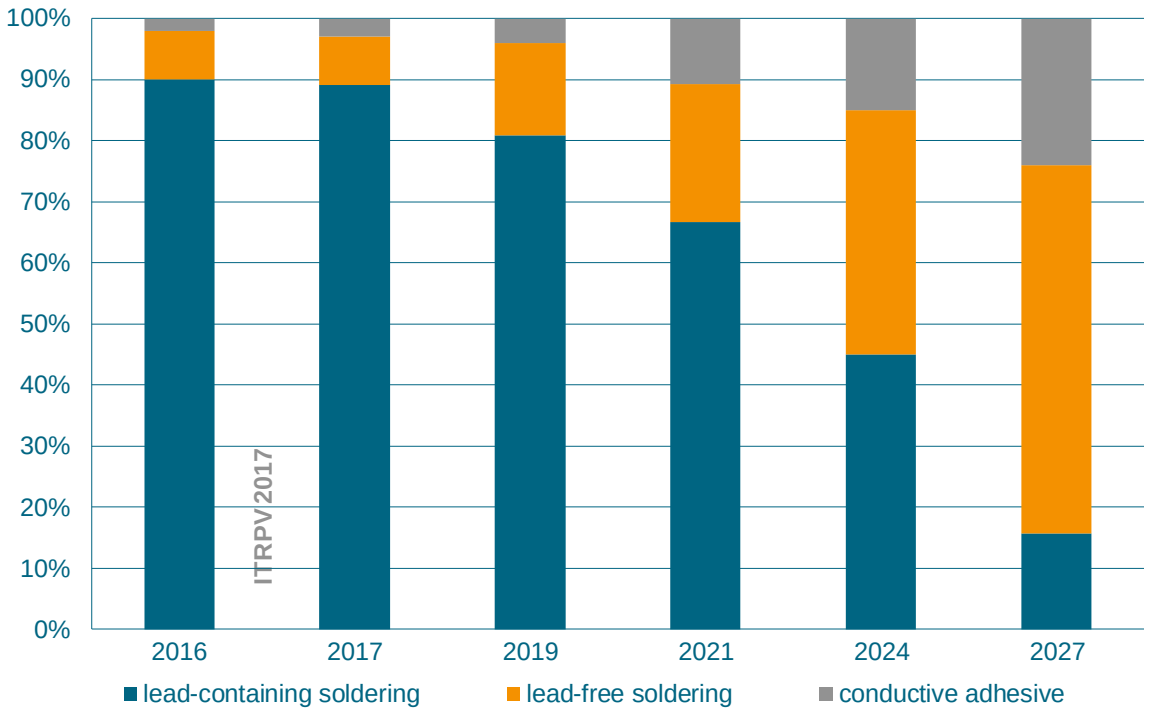


Glas will gain share as back cover material

TPT will lose share on the long run

Module – Processes: interconnection technology

Trend: cell interconnection technology



Expanding market share:
lead free soldering + conductive adhesives

Trend: cell connection material

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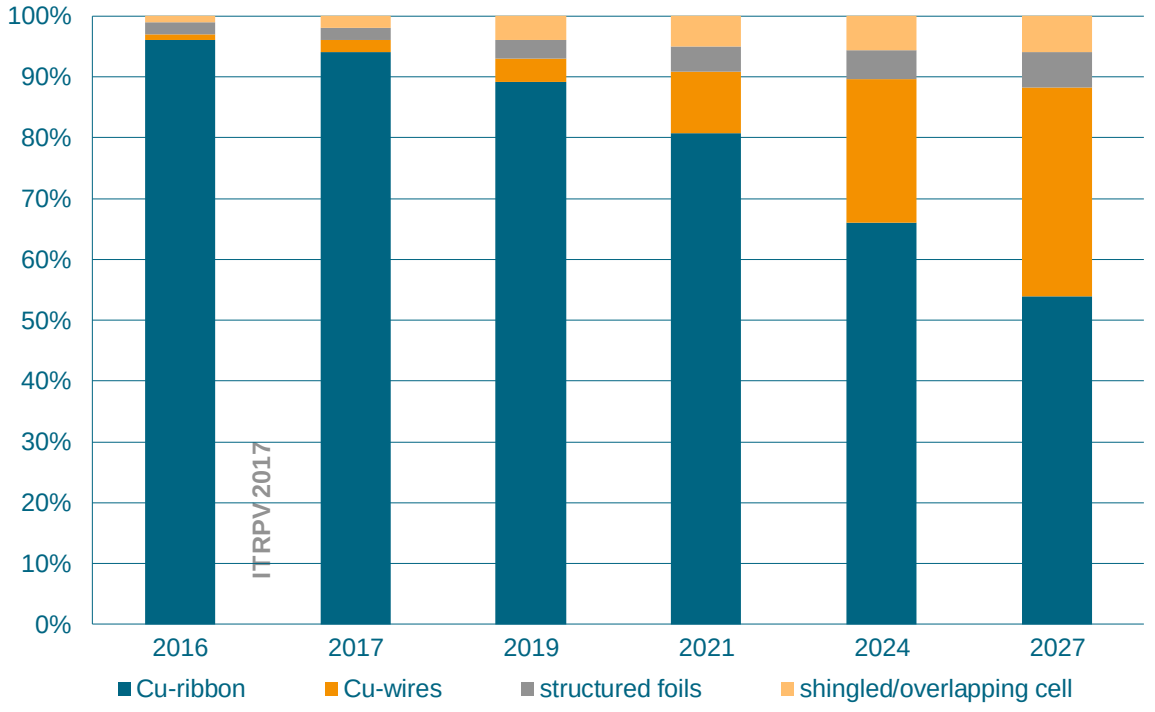
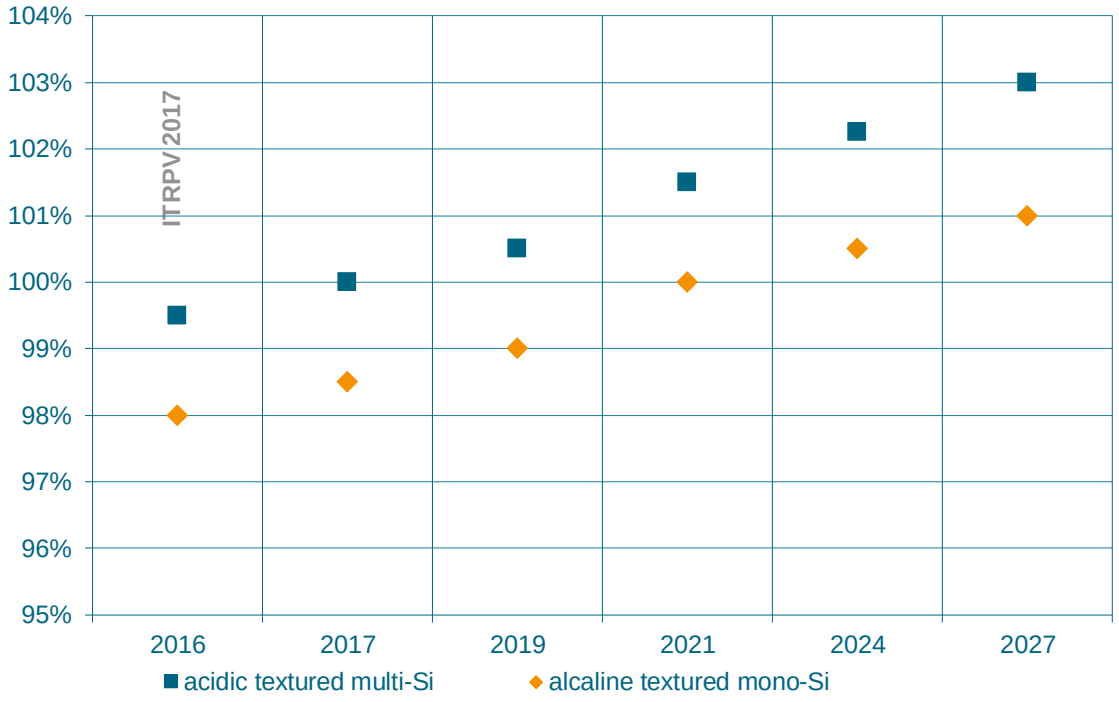


Cu will remain most widely used cell connection material
Cu wires will increase market share

Module – Products: module power outlook

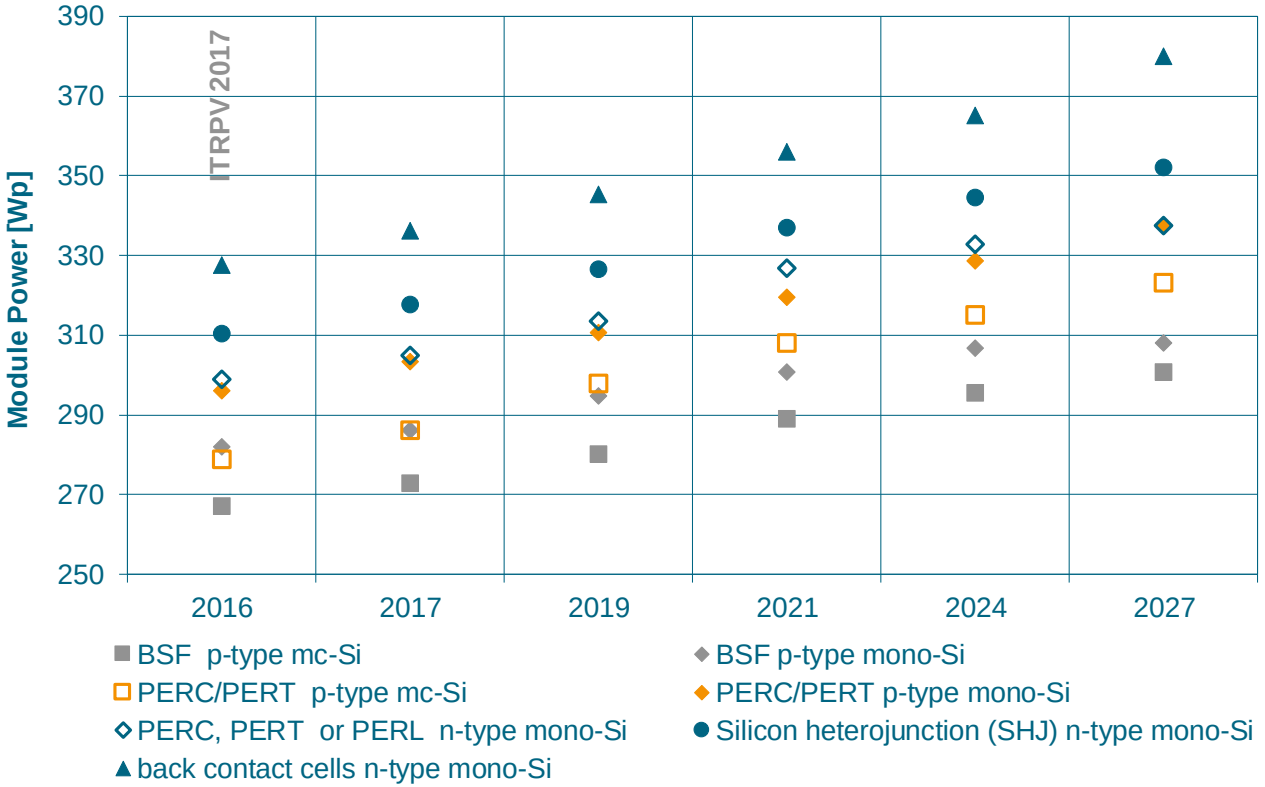
Trend: cell to module power ratio (CTM)



CTM will increase to > 100%

→ Acidic texturing has higher CTM

Trend: module power of 60 cell (156x156mm²)



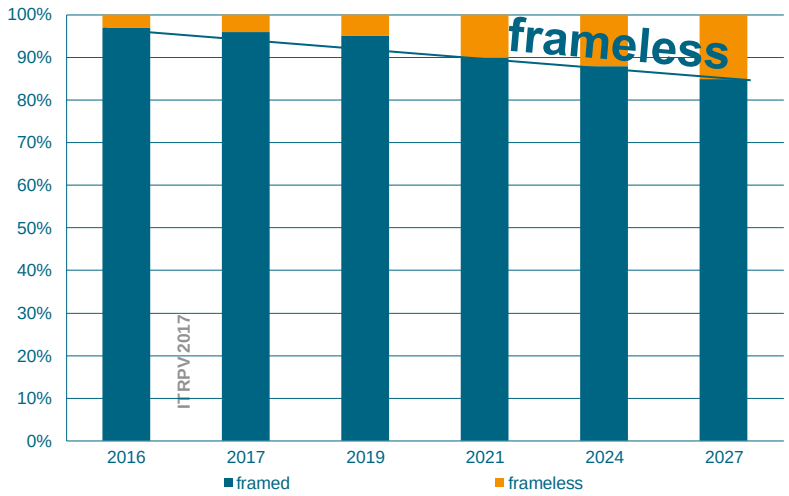
60 cell modules 2017:

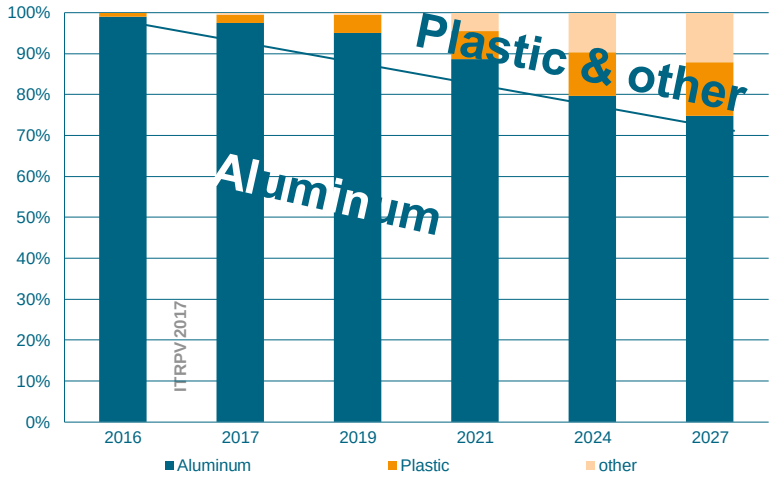
Mono p-type PERX: 300 W are standard

Multi p-type PERX: 285 W are common

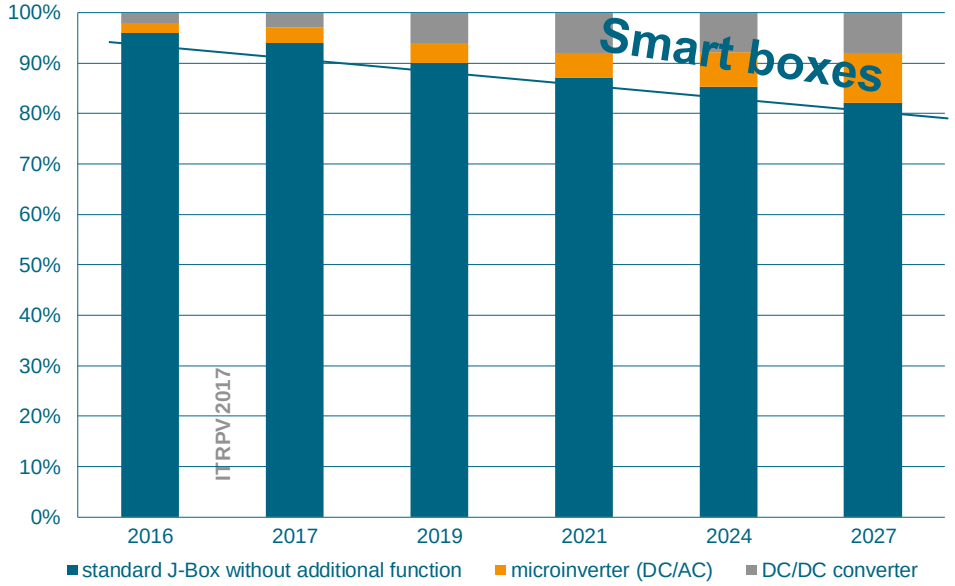
Module – Products: framed modules and J-Boxes

Trend: share of frameless c-Si modules





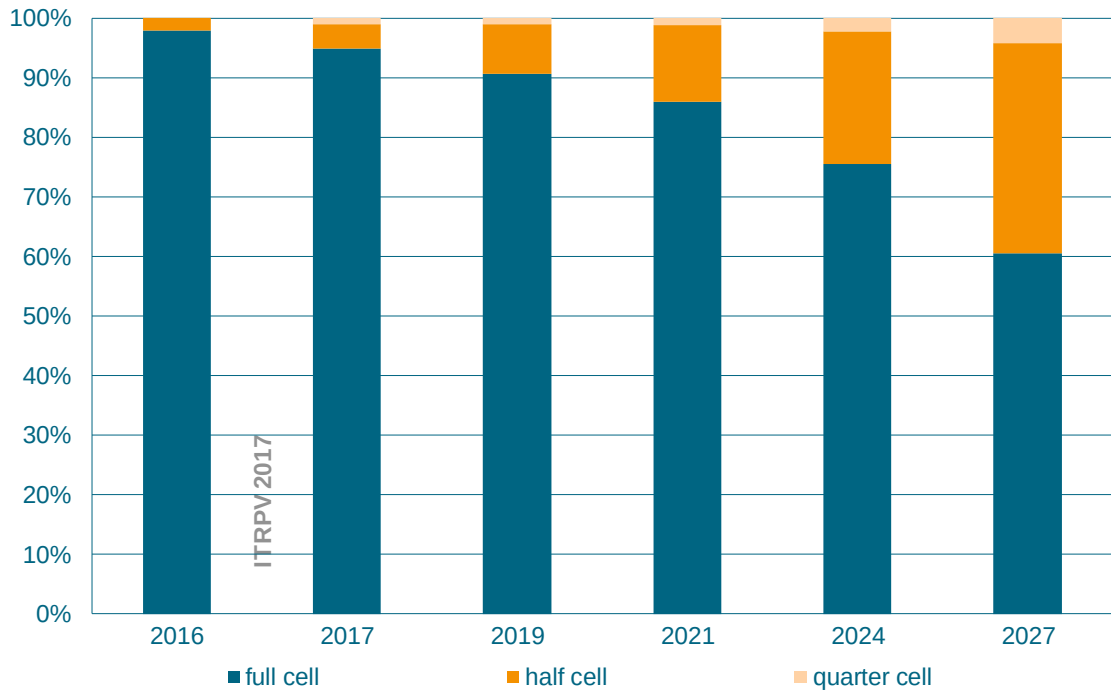
Trend: share of smart J-Boxes



Al-frames will stay mainstream
→ frameless for niche markets
Standard J-Box remains mainstream
Smart J-Boxes for niche applications

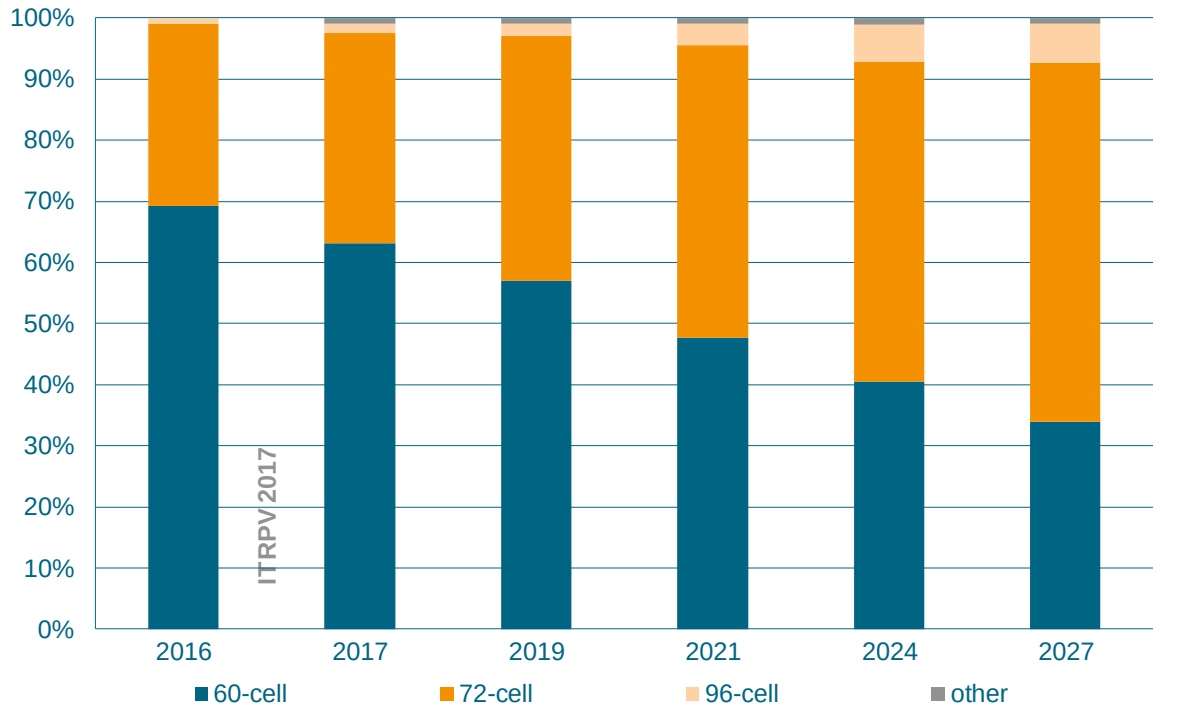
Module – Products: module size

Trend: share of cell dimensions



Full cell will remain main stream
half cell implementation started!
quarter cells – currently a niche

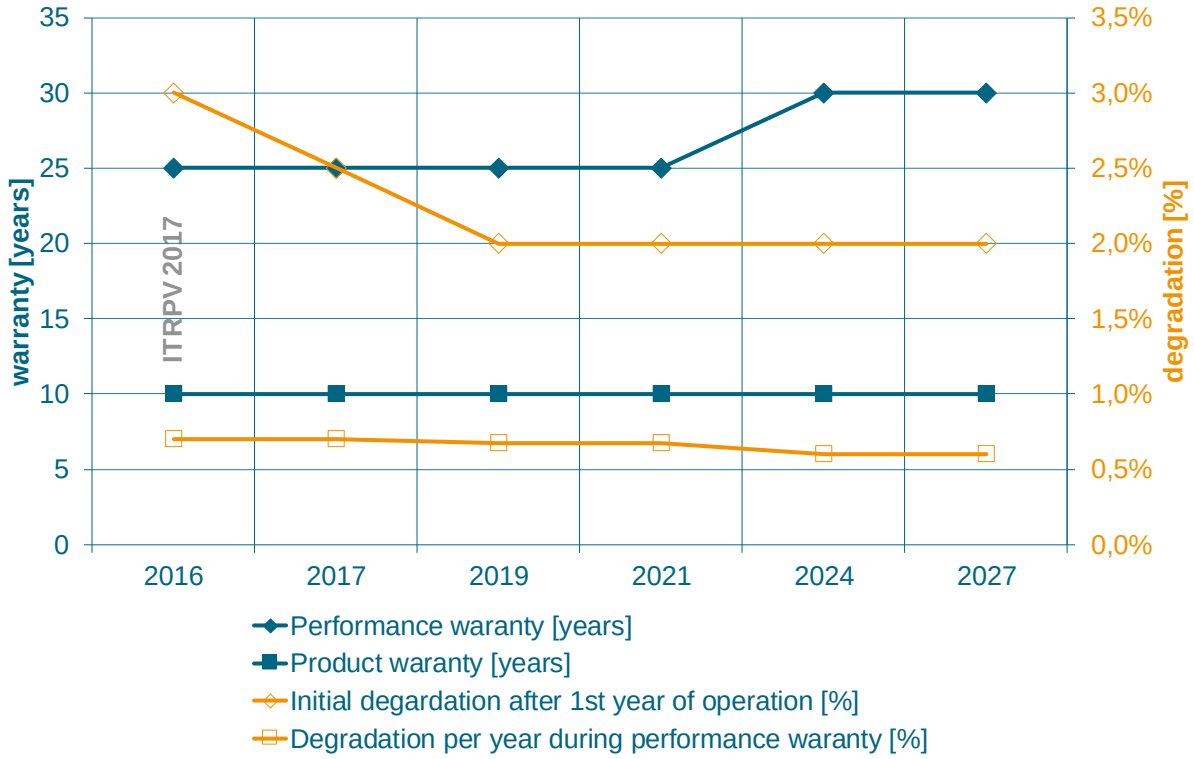
Trend: share of module size (full cell)



Big is beautiful: **72 cell module share will increase**
60 cell modules → mainstream until 2020

Module – Products: module reliability (new)

Trend: warranty conditions and degradation for c-Si modules



Product warranty will remain 10 years

Performance warranty 2024+: 30 years

degradation:	**Initial / linear/year**
2016:	3.0 % / 0.7%
2017:	**2.5 % / 0.68%**
2019+:	**2.0 % / 0.68%**
2021+:	**2.0 % / 0.60%**

Outline

1. ITRPV Introduction
2. PV Learning Curve and Cost Considerations
3. ITRVP – Results 2016
   - Si / Wafer - Materials, Processes, Products
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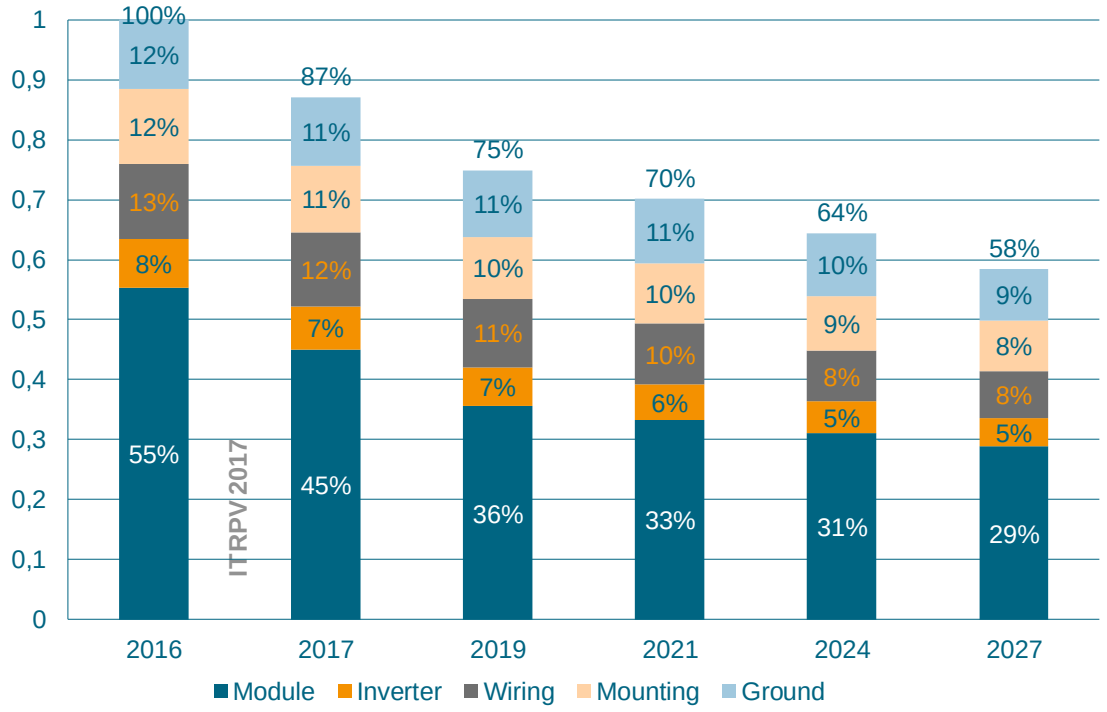
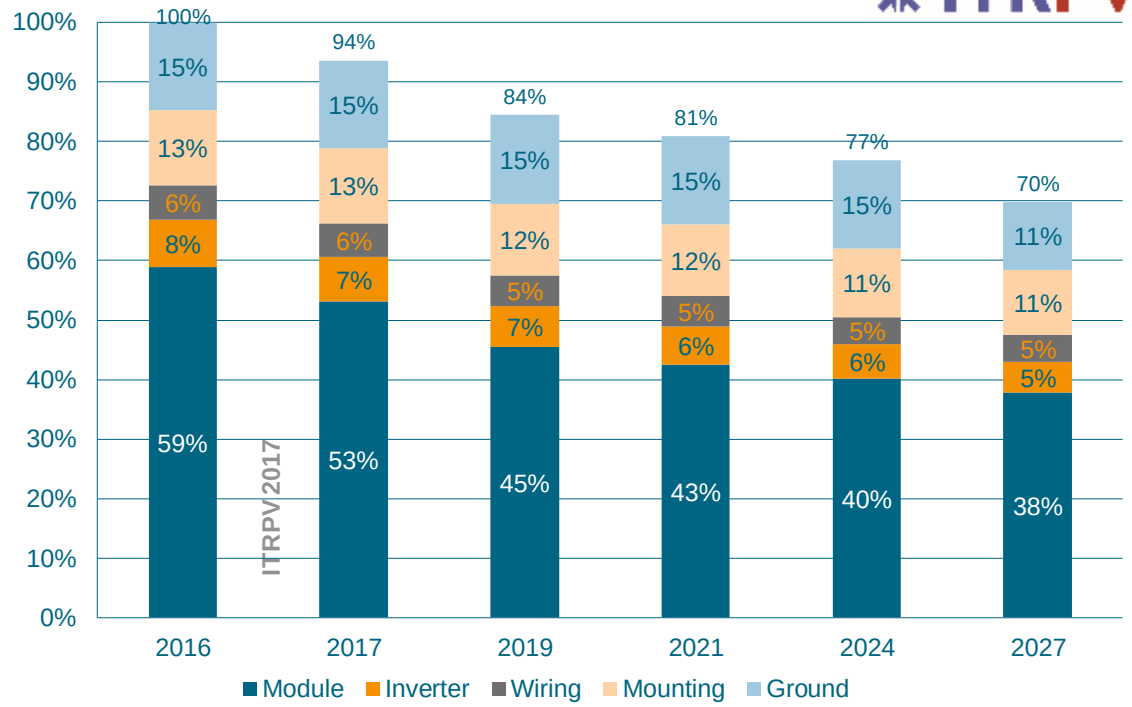
   - Module - Materials, Processes, Products
   - **Systems**
4. Summary and Outlook

Systems – Balance of system (BOS) for power plants

Trend: BOS in Europe and US



Trend: BOS in Asia

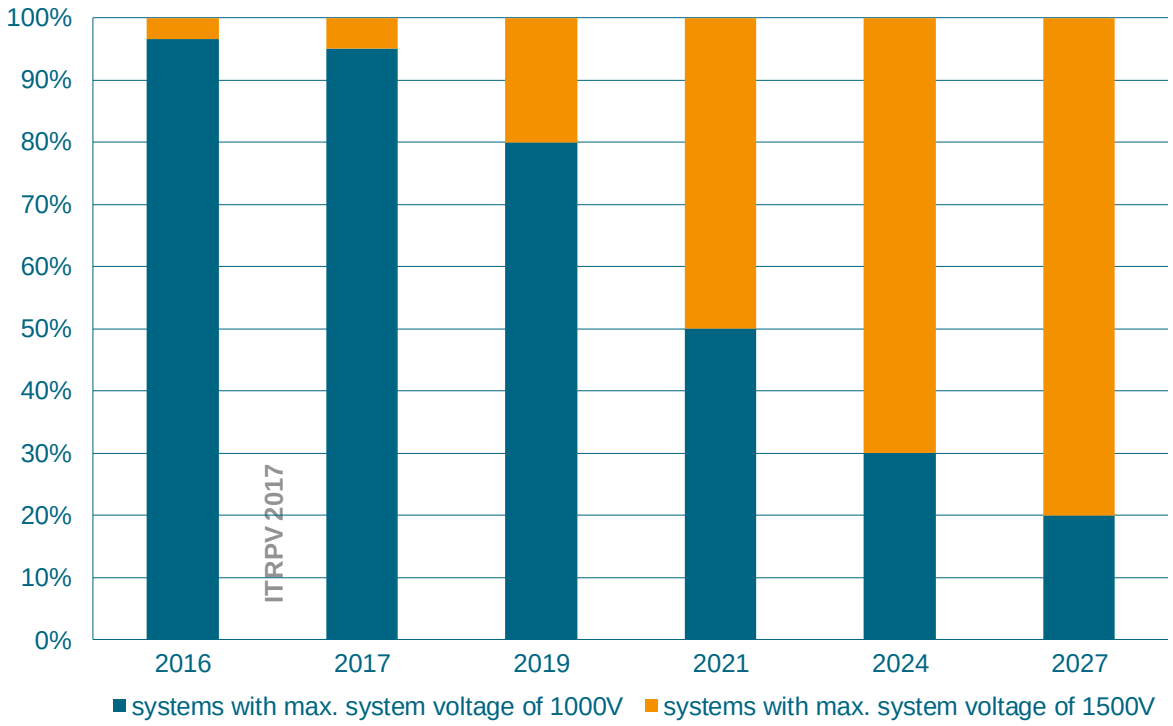


Still significant cost reductions foreseen

Costs in Asia are assumed to be significant lower

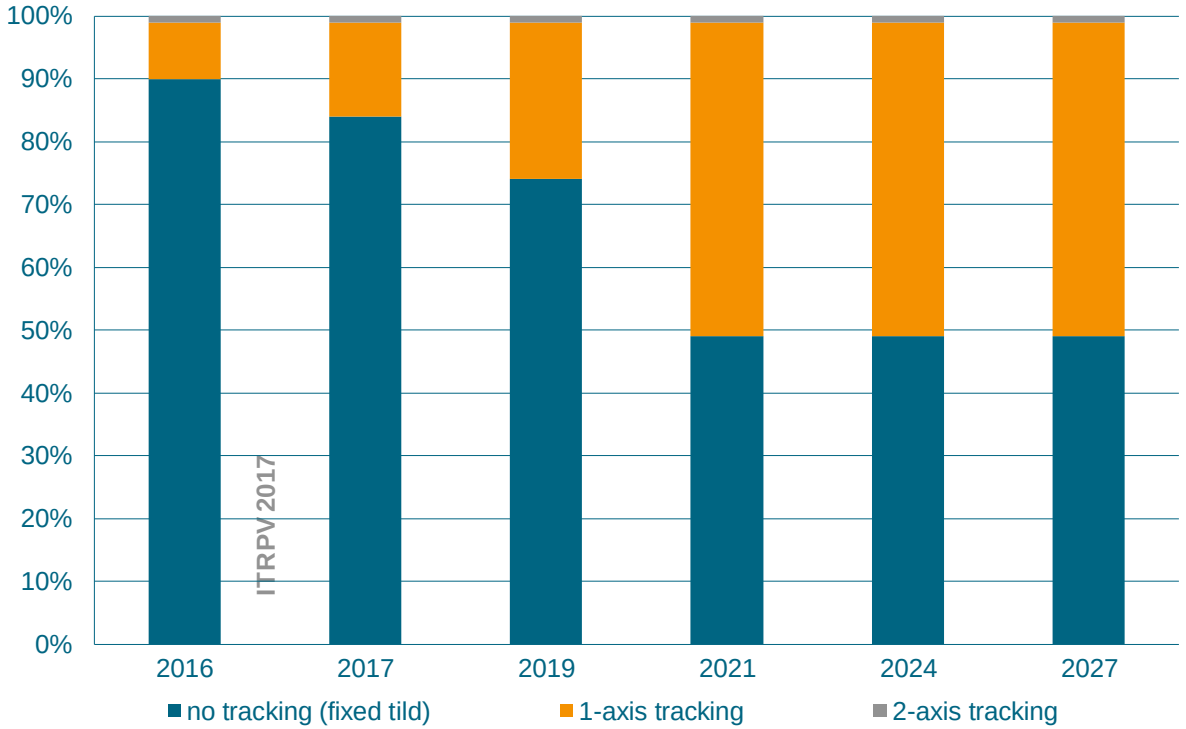
Sstems – Components: system voltage /tracking

Trend: system voltage



1500V are the future

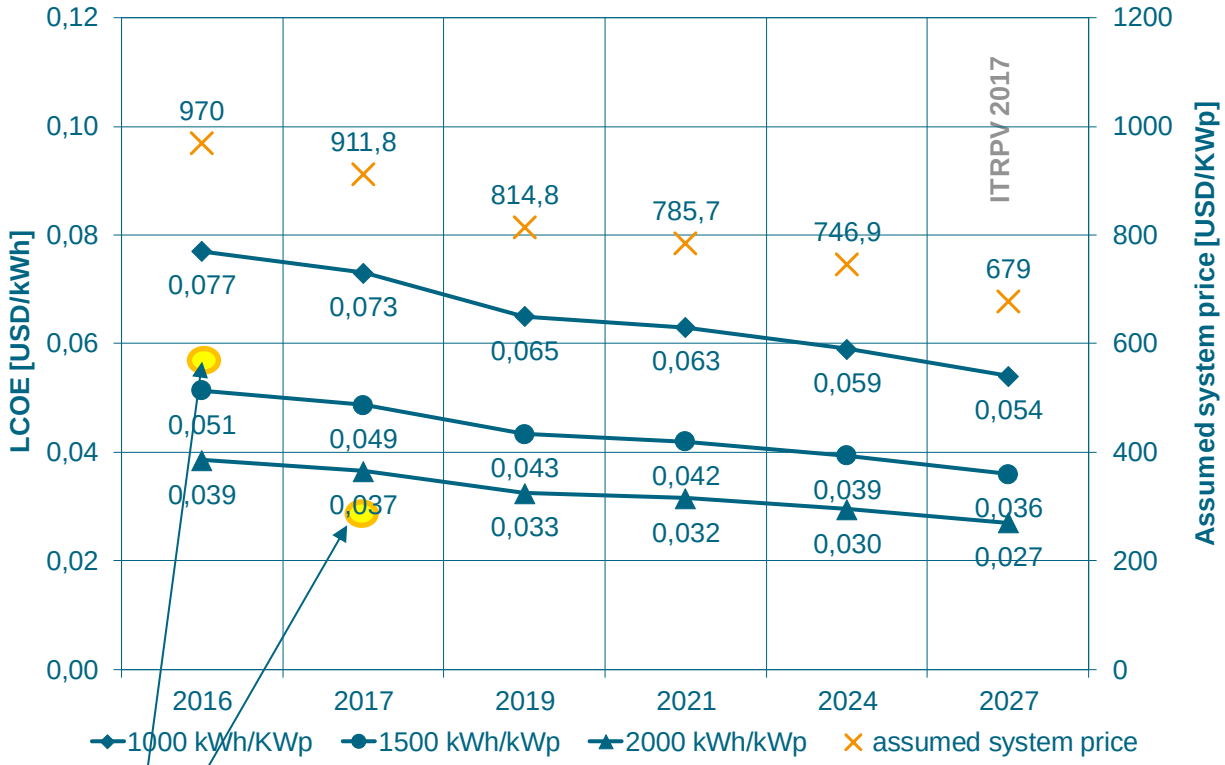
Trend: tracker systems in power plant applications



1-axis trackers will gain market share

Systems – Levelized Cost of Electricity (LCoE)

Trend: LCoE progress – a minimum approach



LCoE depends strongly on local conditions

→ **~5.7 US$ct/kWh lowest auction bidder in GER 2016** (avg. 7.7 $ct)**

→ **~2.42 US$ct/kWh possible near Abu Dhabi* today**

* http://www.pv-tech.org/news/jinkosolar-in-deal-to-build-1.2GWp-solar-plant-in-Abu-Dhabi

** http://www.sunwindenergy.com/photovoltaics/danish-bidders-win-cross-border-pv-tender

System prices

→ 2016: 970 $ / kWp

→ 2027: <680 $ / kWp

LCoE

→ 2016: 3.9 ….. 8 $ct/kWh (GER avg. 7.7 $ct**)

→ **2027: 2.7 ….. 5 $ct/kWh are realistic**

- System live times of 25 years are assumed

Next steps to further reduce LCoE:

→ extended **service live** to **30 years**
(supported by performance warranty trend)

→ further efficiency improvements
+ cost down measures

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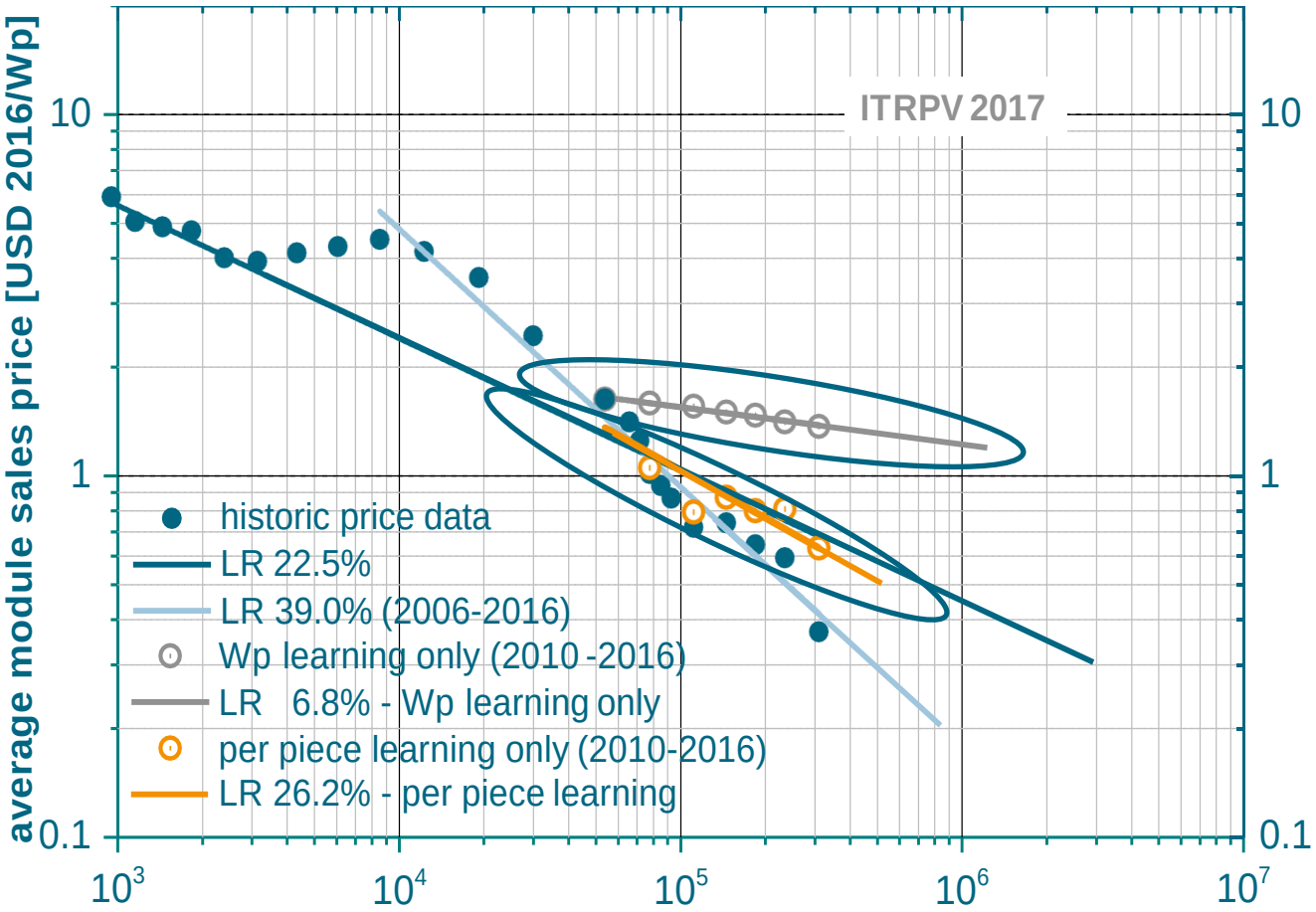
4. **Summary and Outlook**

Outlook: in detail view at PV learning curve

1976-2016: LR= 22.5%
2006-2016: LR= 39.0%



ITRPV finding 2010-2016:

Wp learning ~ 7% (continually)
per piece learning ~26% (market influenced)

→ Learning was and will always be a combination of:

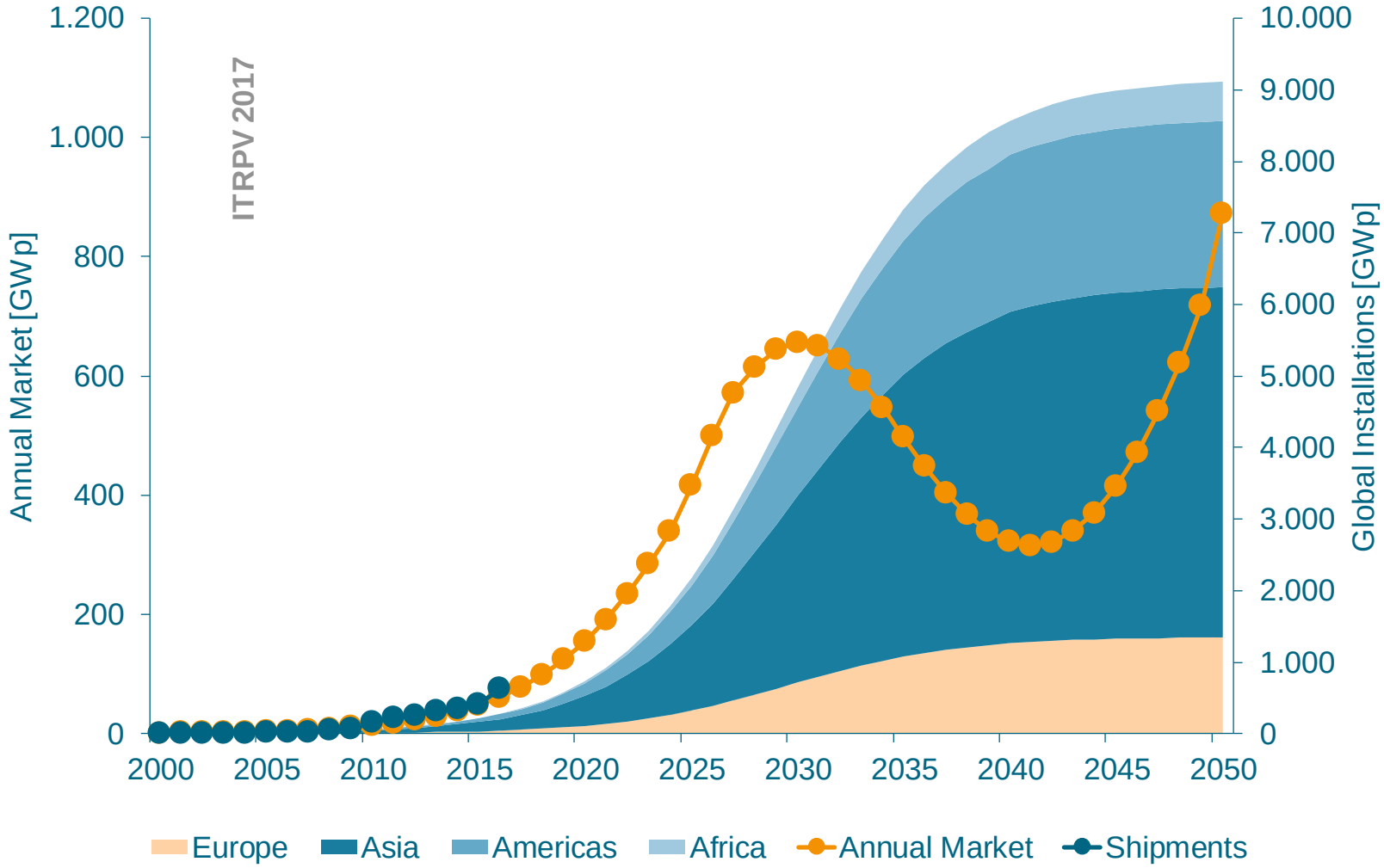
efficiency increase
+ continues cost reduction per piece
= cost reduction of PV generated electricity

But how will PV proceed in future?

Approach: **logistic growth**

PV market trend until 2050: logistic growth

Scenario 3 “high”: 9.2 TWp/ 14.3 PWh (< 10 % primary energy)



Approach: 3 scenarios for 190 different countries in 4 regions Asia / America / Africa / EU

ITRPV finding:

- Shipments until 2016 slightly above all scenarios
- Annual PV market: **335 GWp/a to 800 GWp/a**

→ **Replacement rate = key to overcome down cycles**

→ **Evolutionary technology development works for all scenarios**

Summary

- Silicon PV will remain a fast (evolutionary) developing technology
- Further reductions of c-Si PV manufacturing cost are possible
- Cell efficiency improvements will support significant LCoE reductions
- Quality and reliability of components and systems are of highest importance

=> Silicon PV will significantly contribute to future power supply

=> We are just at the beginning of PV-market development


Source: www.siemens.com/presse

Thank you
for your attention!

Contact us:

jutta.trube@vdma.org

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