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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

ITRPV Workshop
Munich, June 1st 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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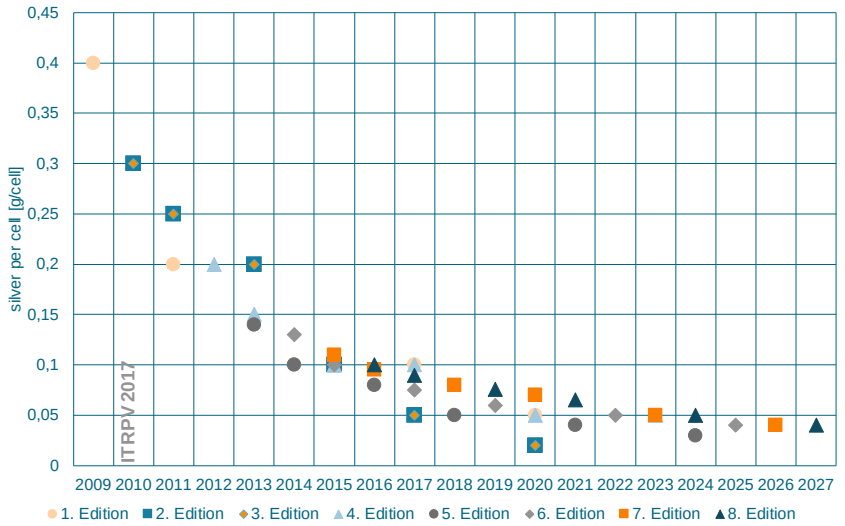
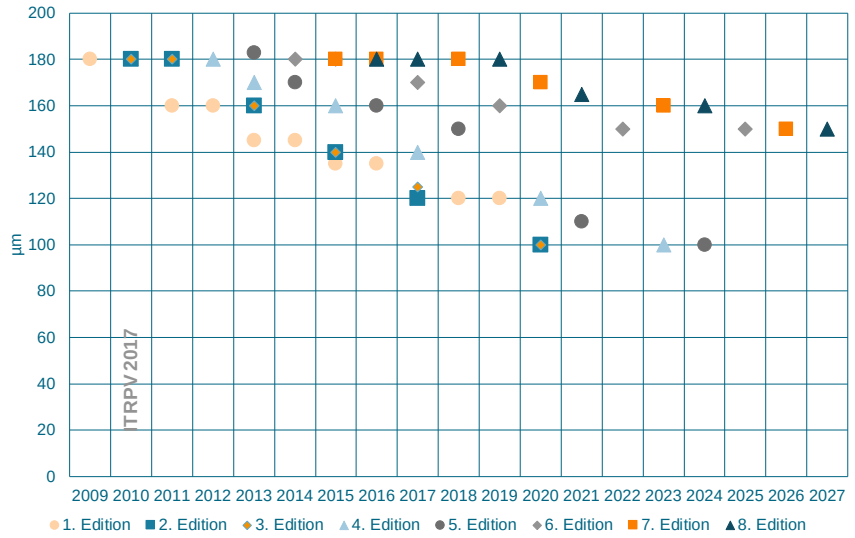
ITRPV 8th Edition 2017 – some statistics

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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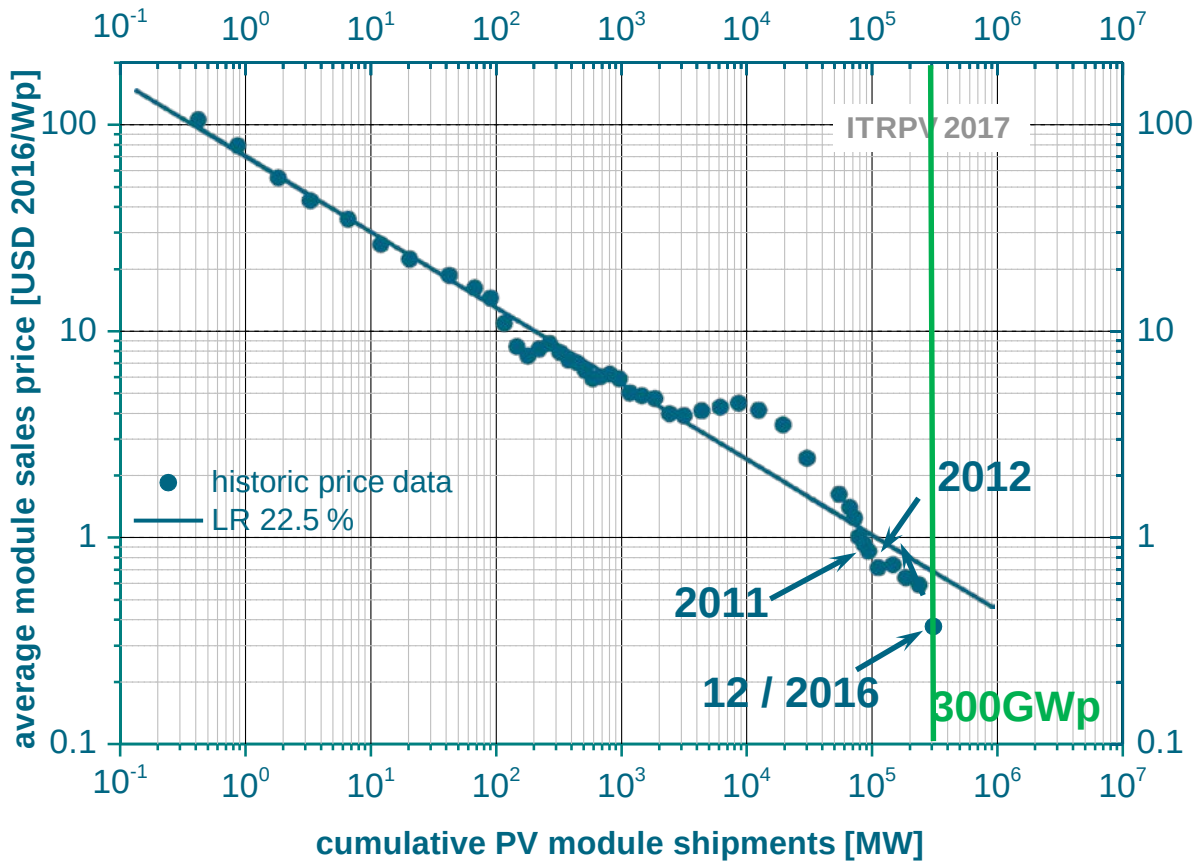
PV learning Curve



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

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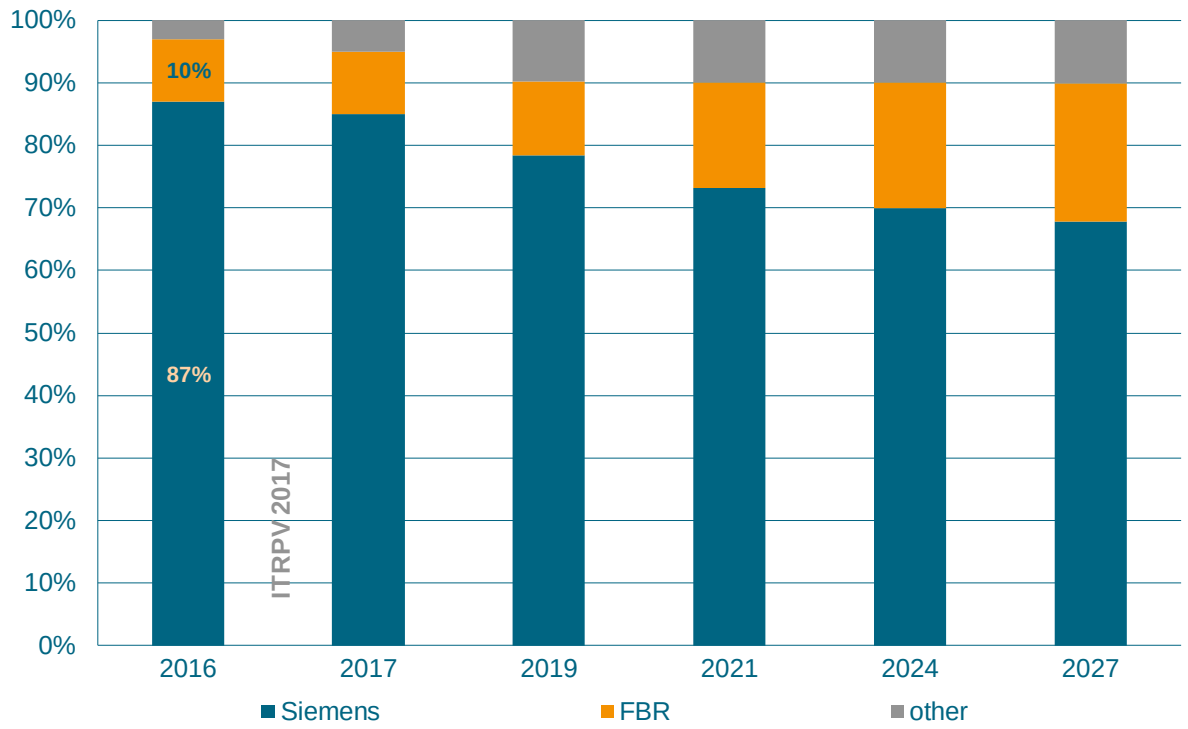
Silicon – Materials: Poly Si Feedstock Technology

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

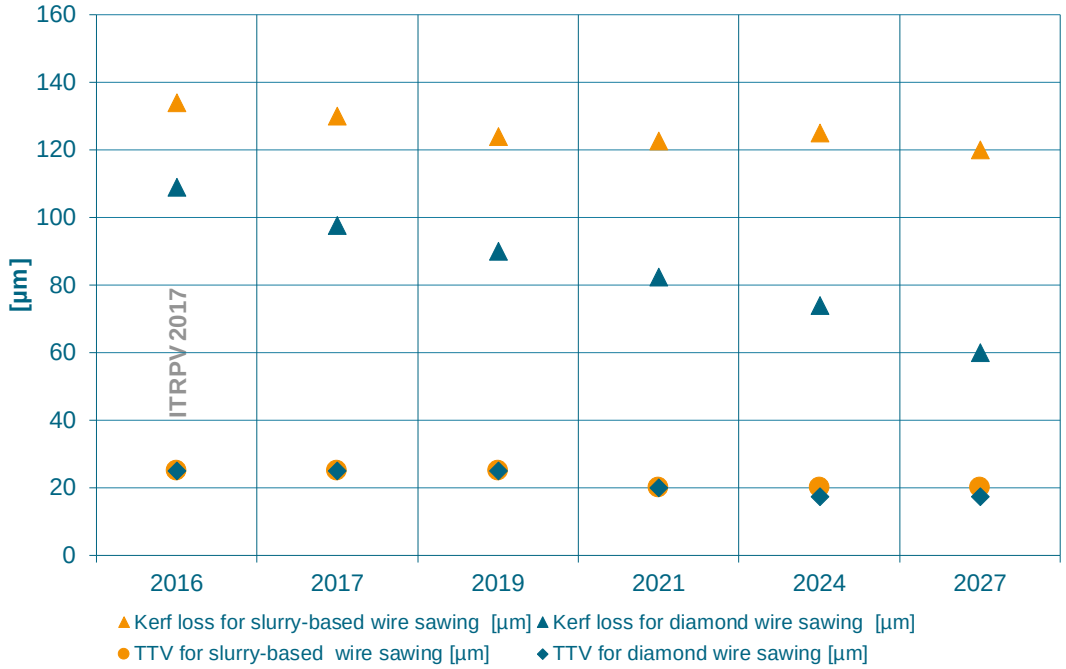
→ Siemens process will remain mainstream
FBR shows potential for cost reduction

→ **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

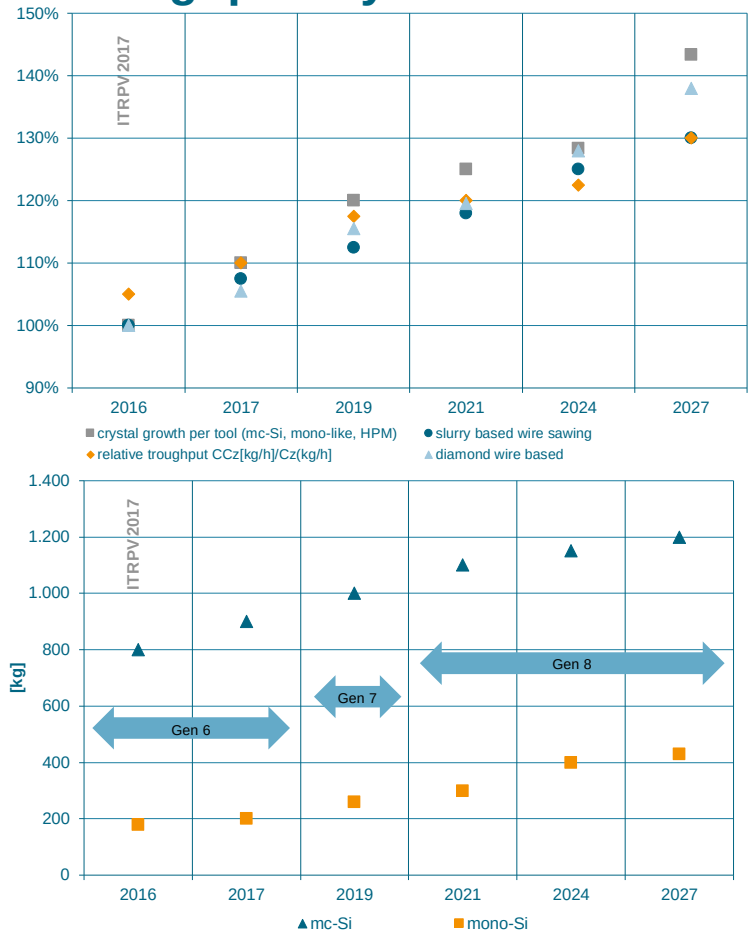


diamond wire sawing advantage:

→ enable faster kerf reduction

No big change in thickness variation is expected

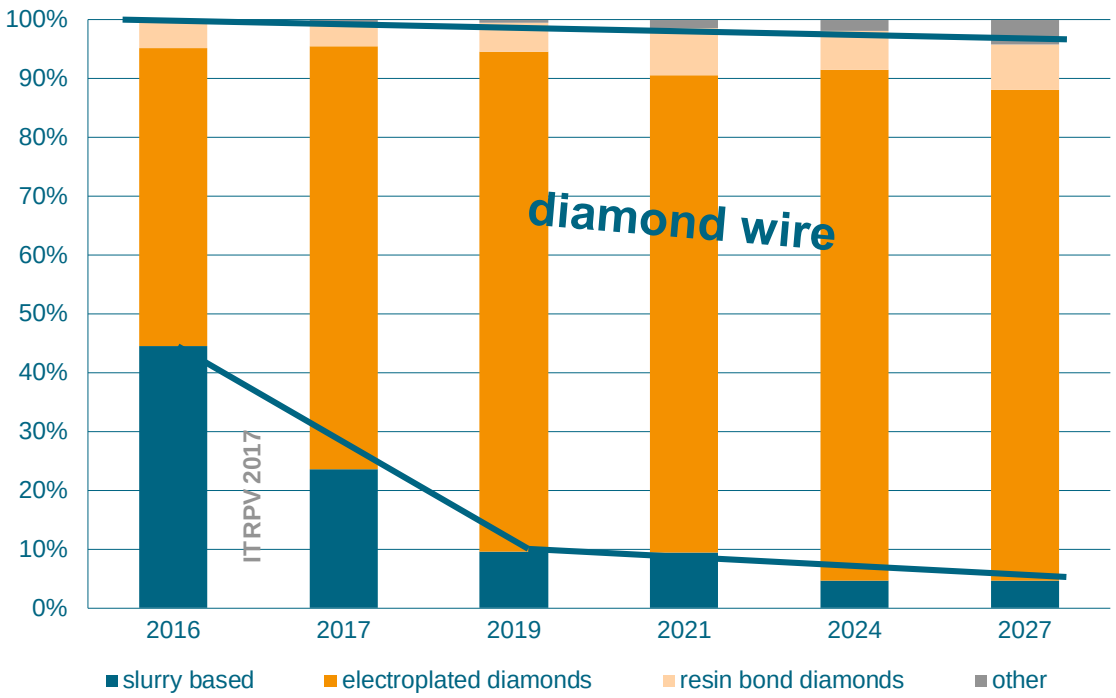
Trend: throughput crystallization/ wafering



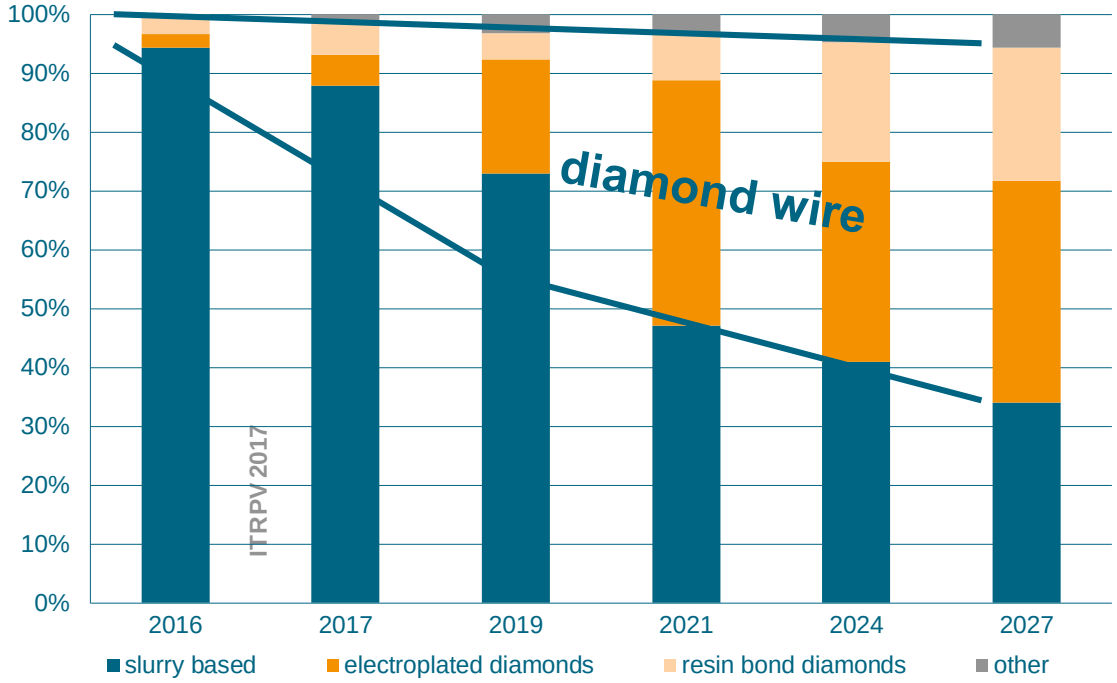
→ Throughput increase in crystallization/wafering will continue

Wafer – Processes: wafering technology (2)

For mono-Si



For mc-Si

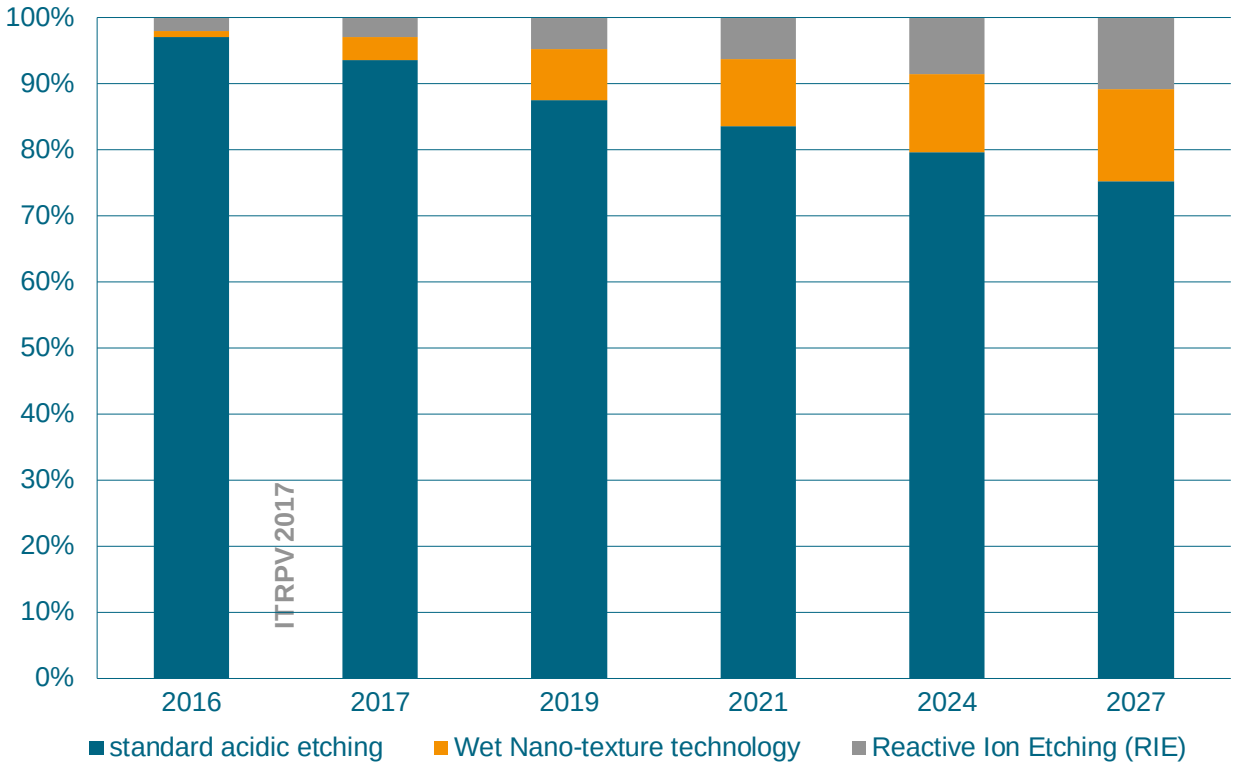


diamond wire wafering now mainstream for mono-Si
→ Throughut 2x – 3x faster than slurry based

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

Wafer – Processes: texturing of mc-Si wafers

Trend: market share of mc-Si texturing technologies

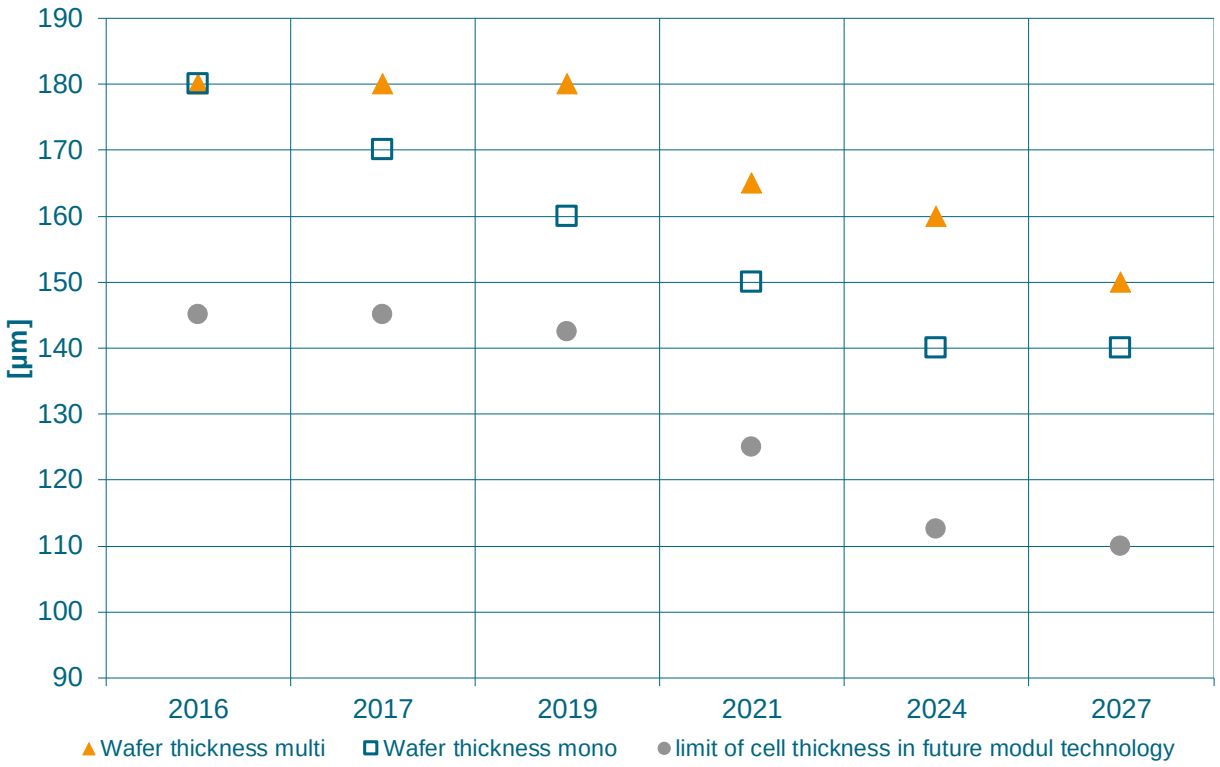


- Acidic texturing is:
  → mature and high throughput process
  → changes in “standard” will appear
- Next step:
  → wet nano texturing, esp. for diamond wire
- RIE share is expected to increase **“but”**
  → no cost efficient alternative

→ Wet processing remains mainstream in mc-Si texturing

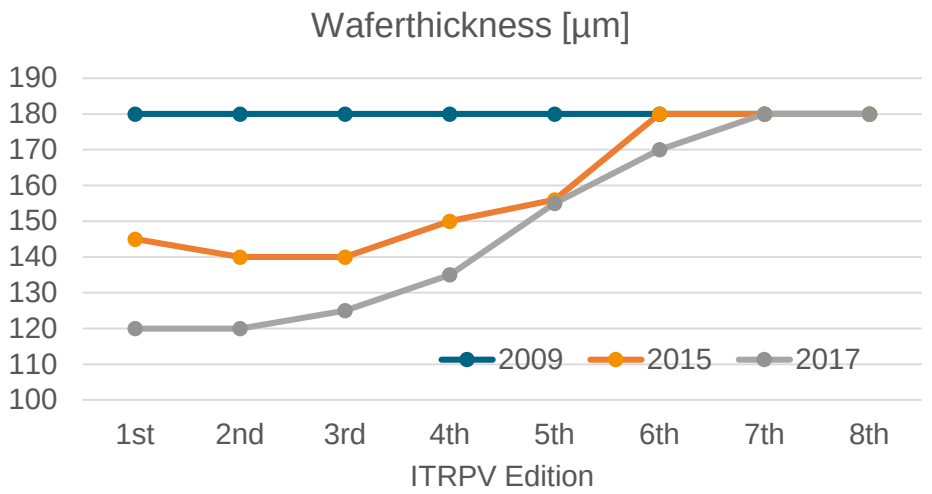
Wafer – Product: thickness trend

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



Mono wafer: thickness reduction starts

- Still no progress in mc-Si thickness reduction



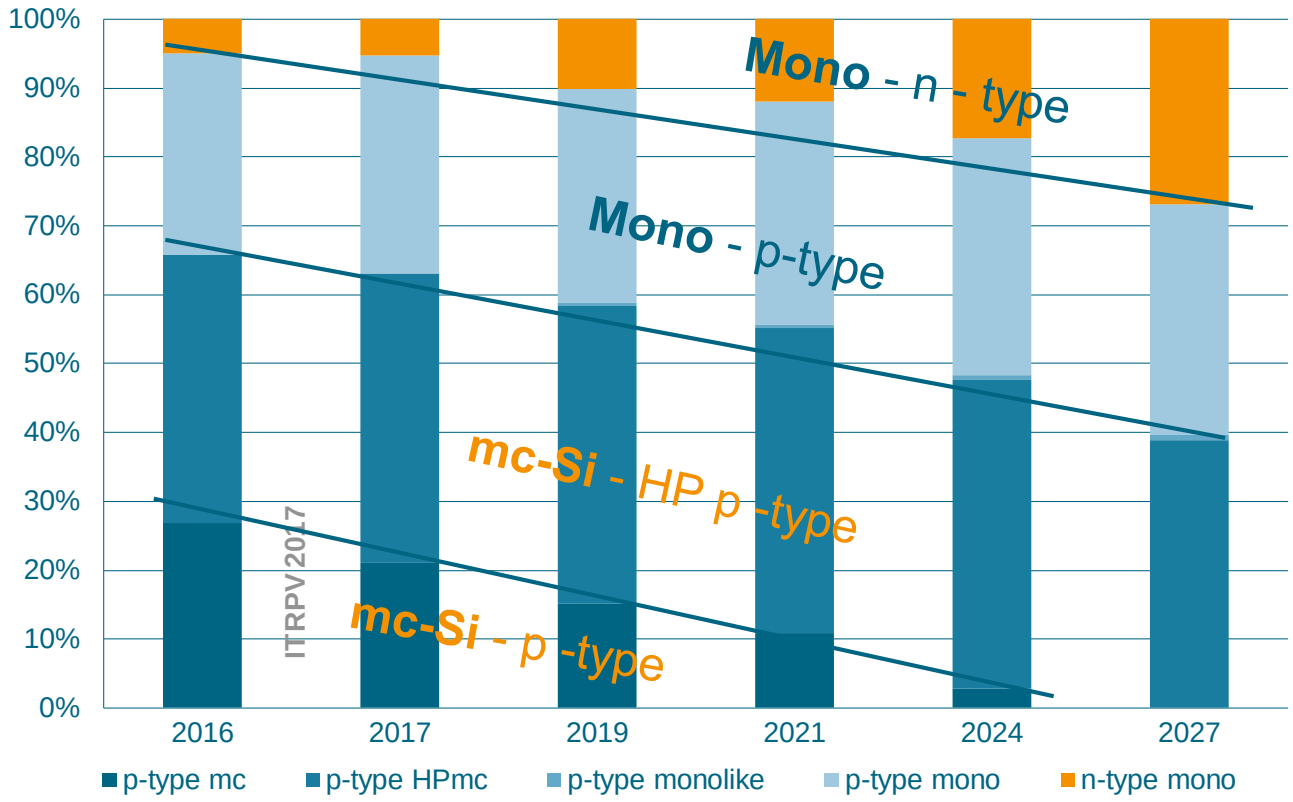
→ 180µm = preferred thickness since 2009

- 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

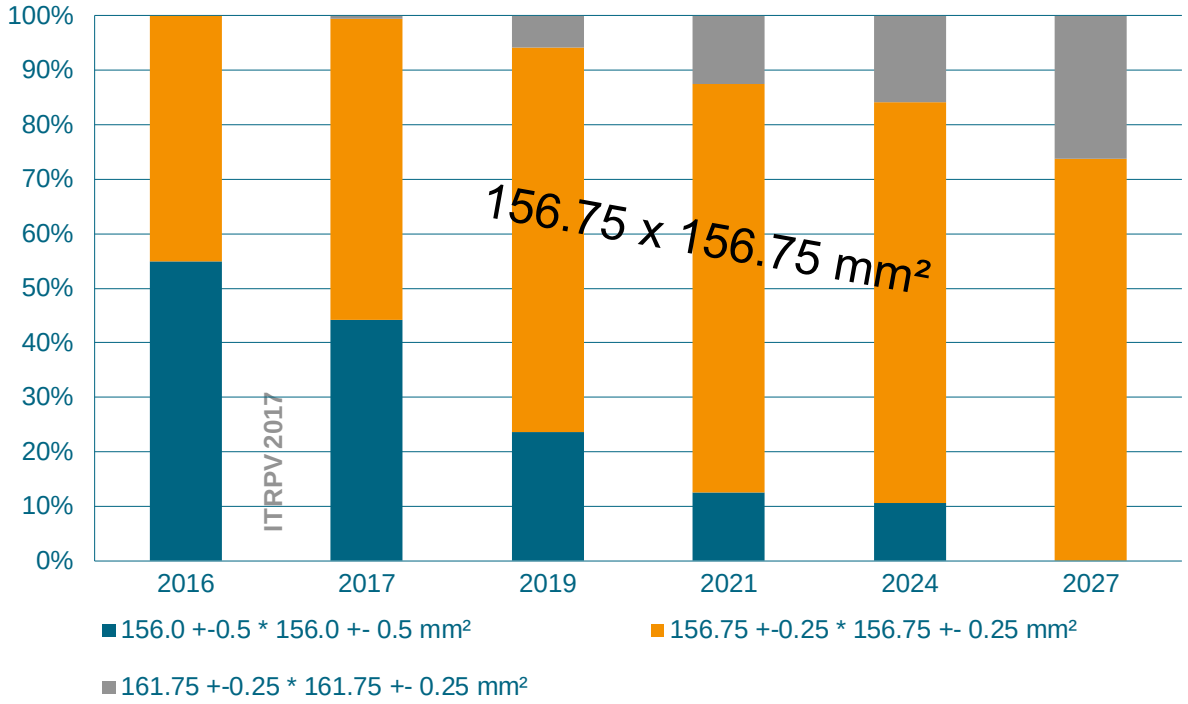
- **Casting technology:**
  → HP mc-Si will replace standard mc-Si
  → no “come back” of mono-like expected

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

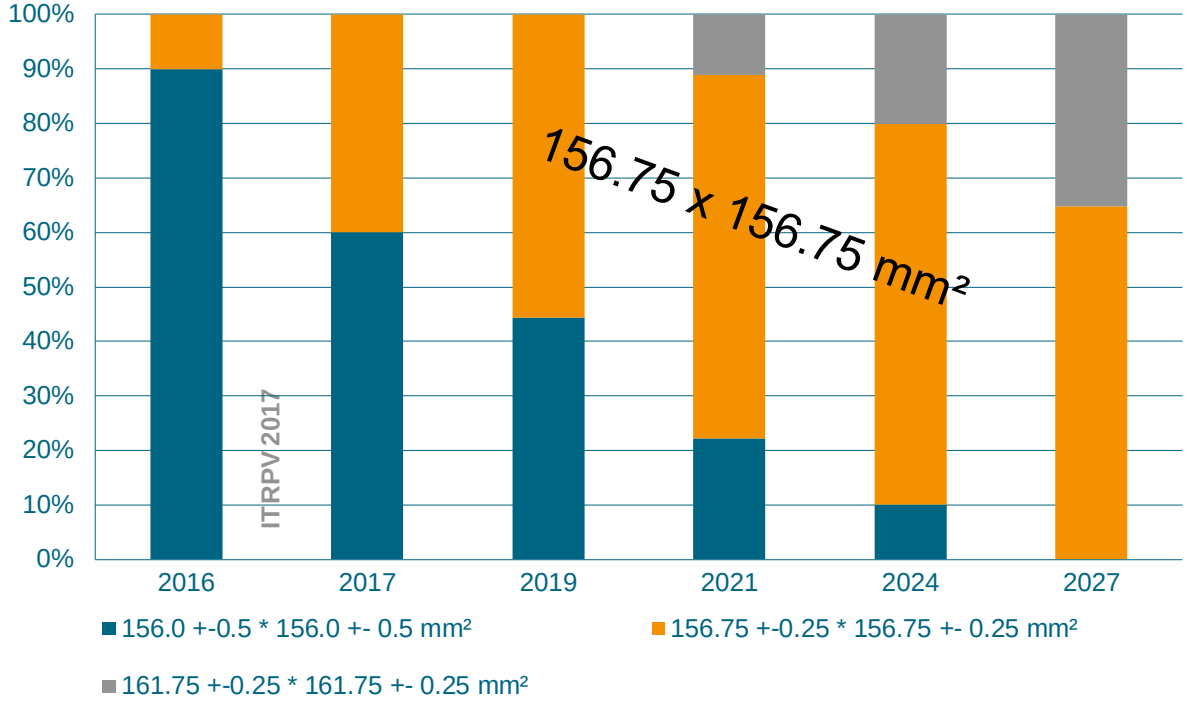
- **p-type material is expected to stay dominant**
  → mainly due to progress in stabilization

Wafer – market share of wafer dimensions (new)

Trend: mono-Si



Trend: mc-Si



Fast switch to new format:

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

Transition to new format in 2017

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

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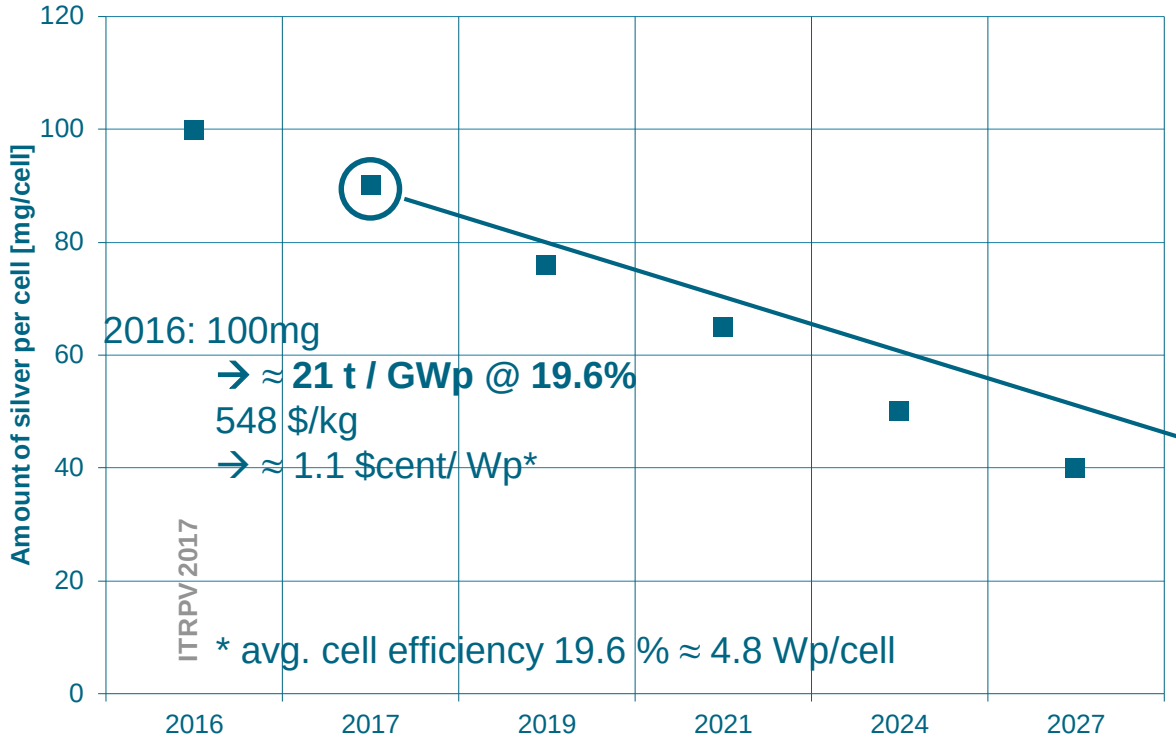
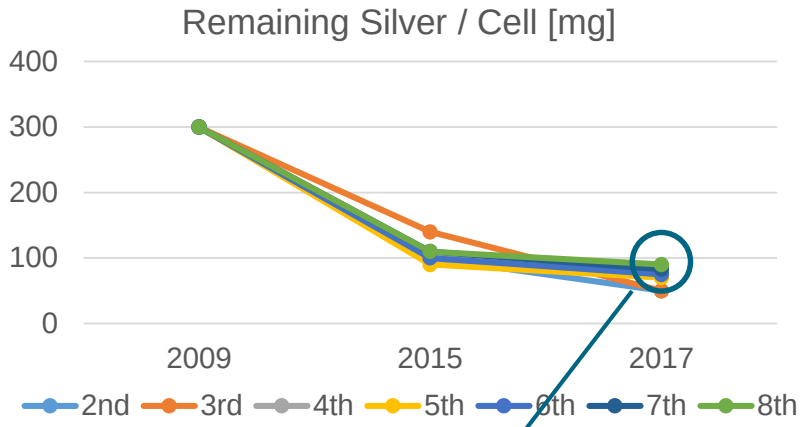
Cell – Materials: Silver (Ag) per cell



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

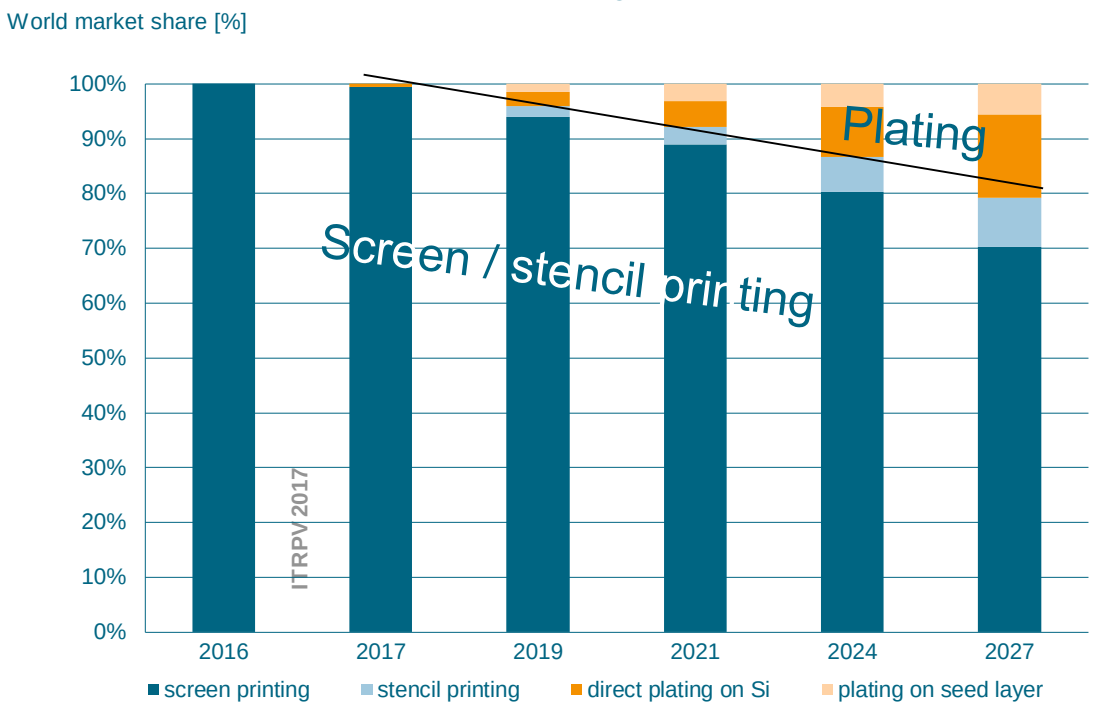
- Ag reduction is mandatory and continues
- delays substitution by Cu or other material

Ag will stay main metallization in c-Si technology

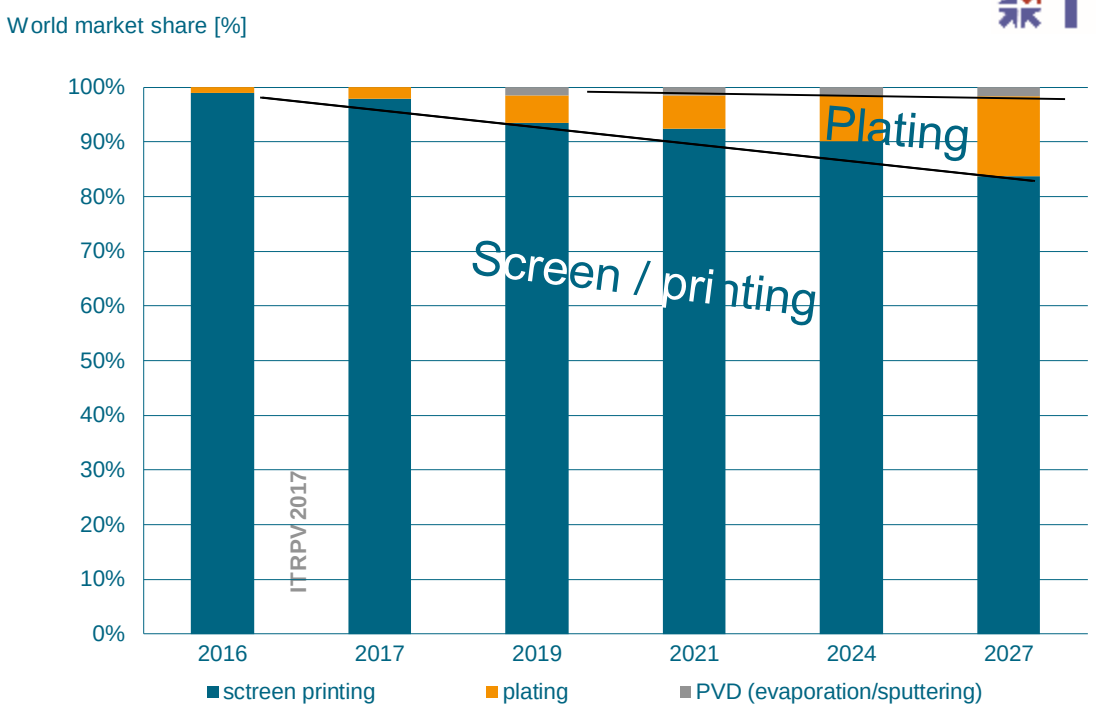
No break through for lead free pastes so far
→ Market introduction depends on performance

Cell – processes: c-Si metallization technologies

Front side metallization technologies



Rear side metallization technologies



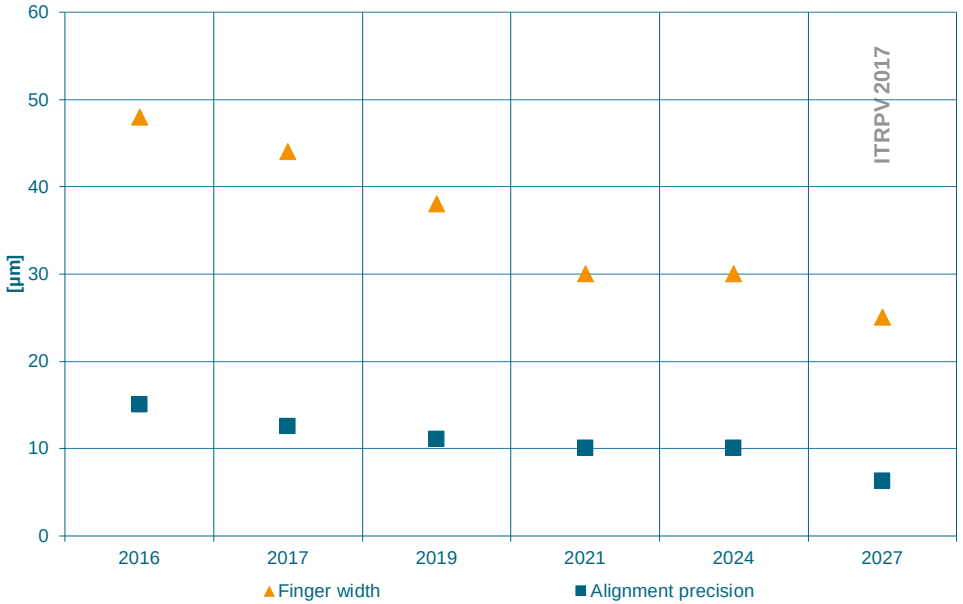
Screen printing remains main stream metallization technology

→ 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**

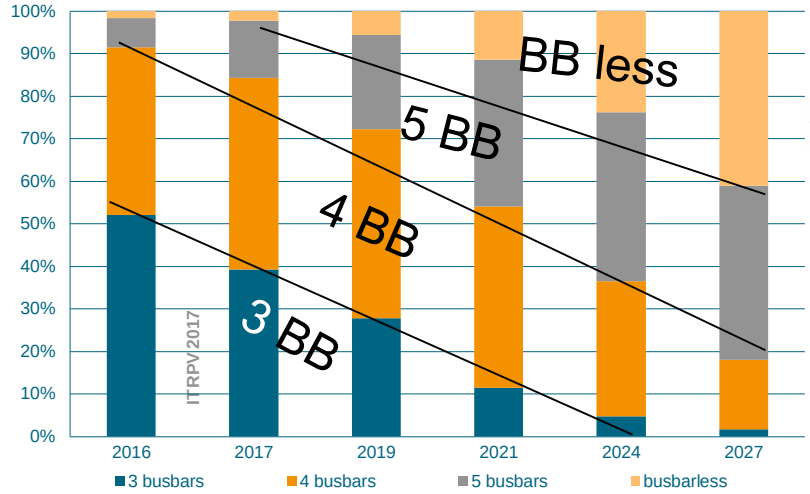
→ 4BB are mainstream – 3 BB will disappear

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

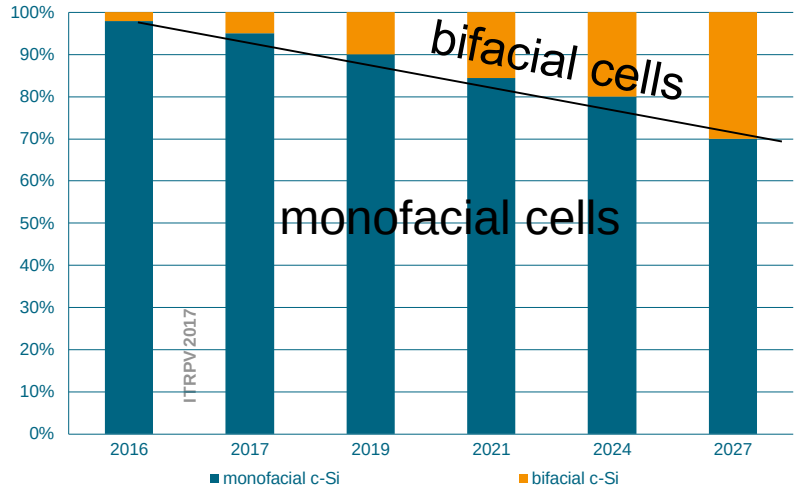
→ Selective emitters + Bifacial cells require good alignment

→ **Bifacial cells will increase market share**

Trend: number of bus bars (BB)

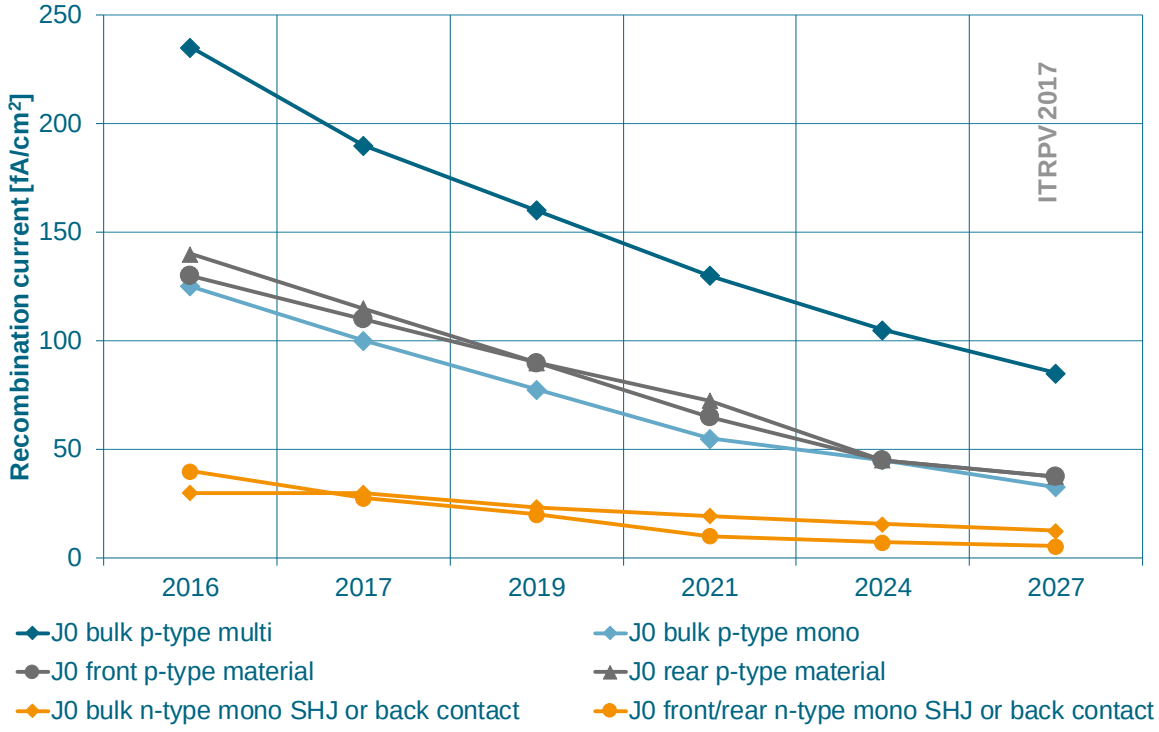


Trend: market share of bifacial cells



Cell – processes: recombination current densities

Trend: $J0_{bulk}$, $J0_{front}$, $J0_{rear}$



$J0_{bulk}$
will be further reduced by optimizing crystallization

	2010	2016
→ p-type mc-Si:	650 →	240 fA/cm²

further reductions will appear:

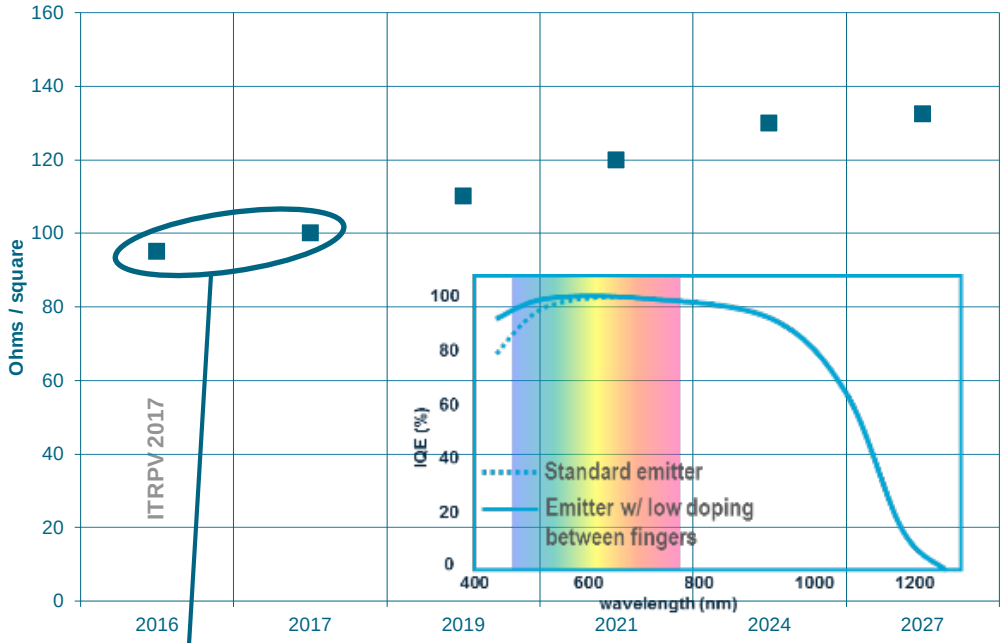
	2016	2017	2027
→ p-type mc-Si:	240 →	180 →	80 fA/cm²
→ p-type mono-Si:	125 →	100 →	30 fA/cm²
→ n-type mono-Si:	25 =	25 →	15 fA/cm²

$J0_{front}$ / $J0_{rear}$
- → Further reductions by > 50% to < 50 fA/cm²
- → p-type improvements are limited at the front side (i.e. need of improved diffusion / new pastes)
- → Wide use of rear side passivation concepts

→ p-type: reducing recombination losses is on a good way
→ n-type: overcomes p-type bulk material limitations

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

Trend: emitter sheet resistance



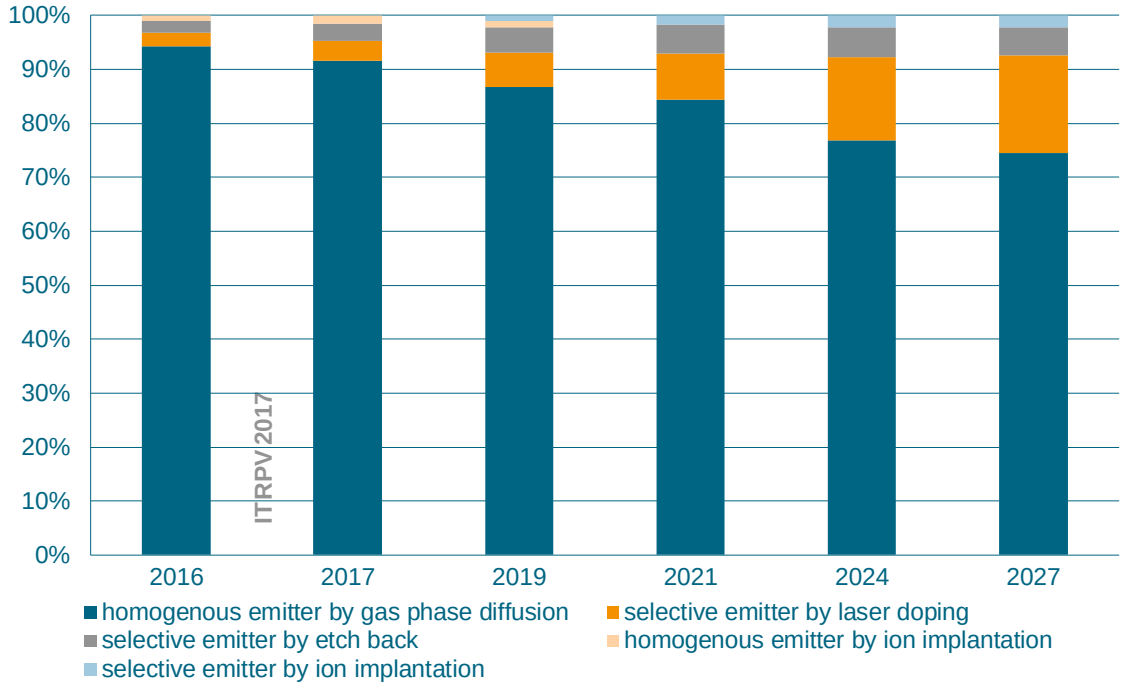
Essential parameter for J0front

→ **95…100 Ω/□** are standard today

→ Increase to 135 Ω/□ is predicted

→ **Challenge for tools and front pastes**

Trend: emitter formation technologies



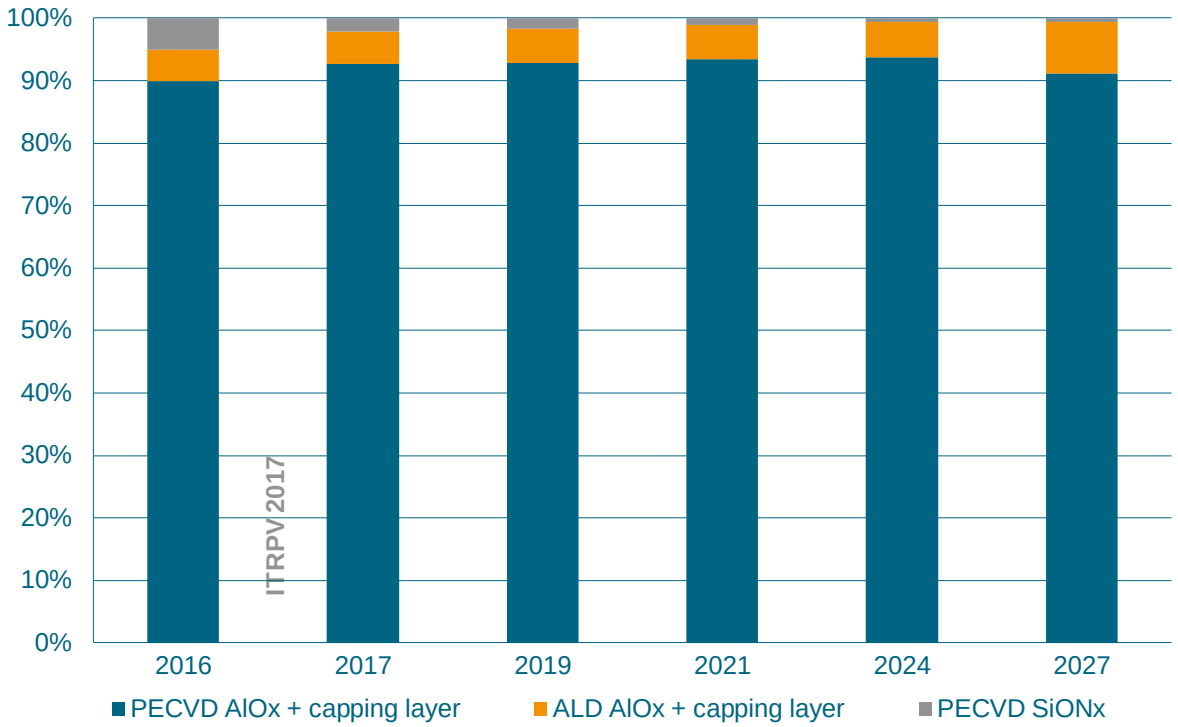
Mainstream: homogenous gas-phase diffusion

→ selective doping: etch back or laser doping

→ Ion implant stays niche

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

Trend: rear side passivation technologies



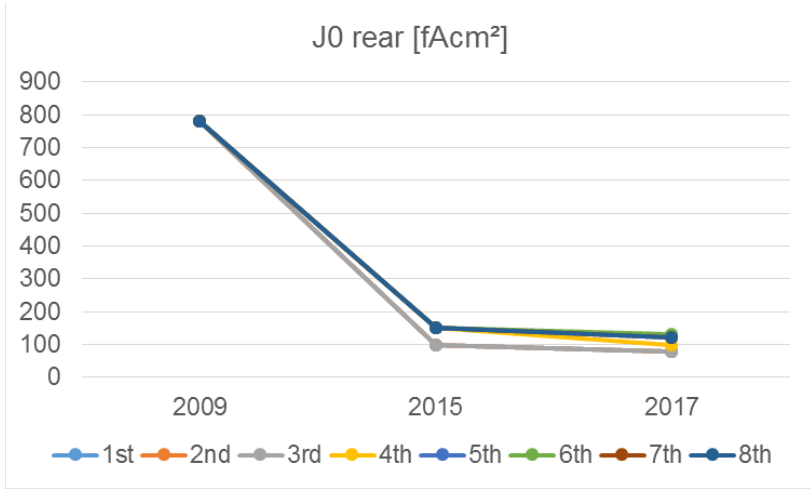
Rear side passivation is mandatory for PERC

→ **PECVD AlOx will stay mainstream**

→ ALD will hold up to 10 %

→ SiONx will disappear

ITRPV prediction for $J0_{rear}$ were good



ITRPV

2009 2017

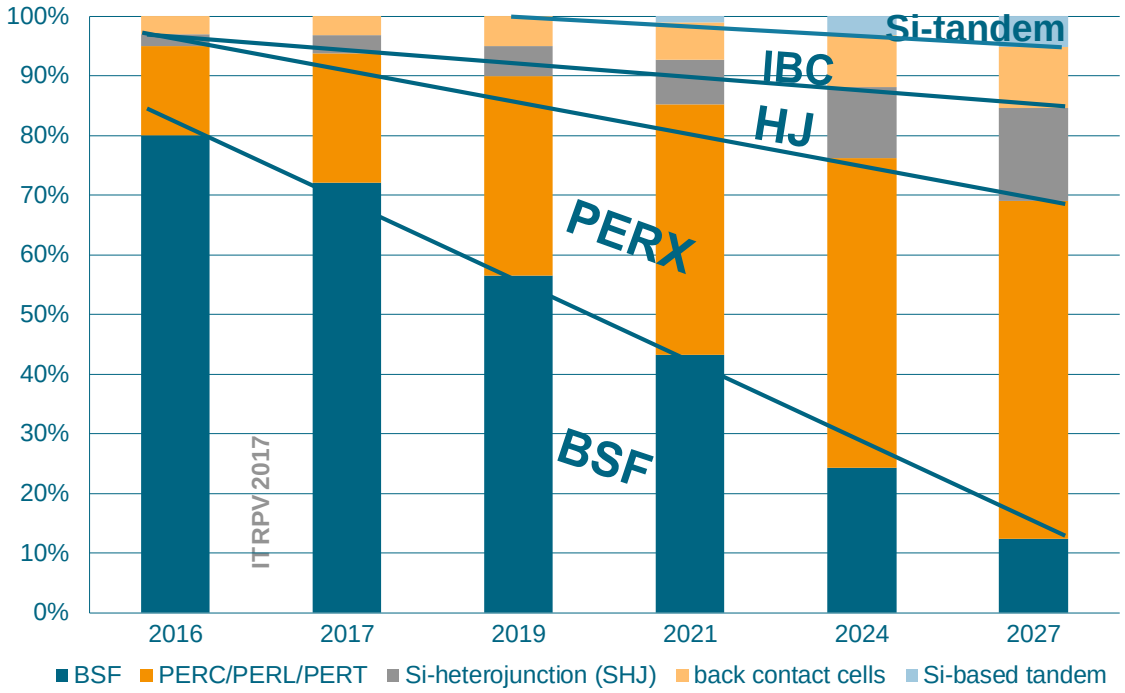
780 → 120 fA/cm²

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

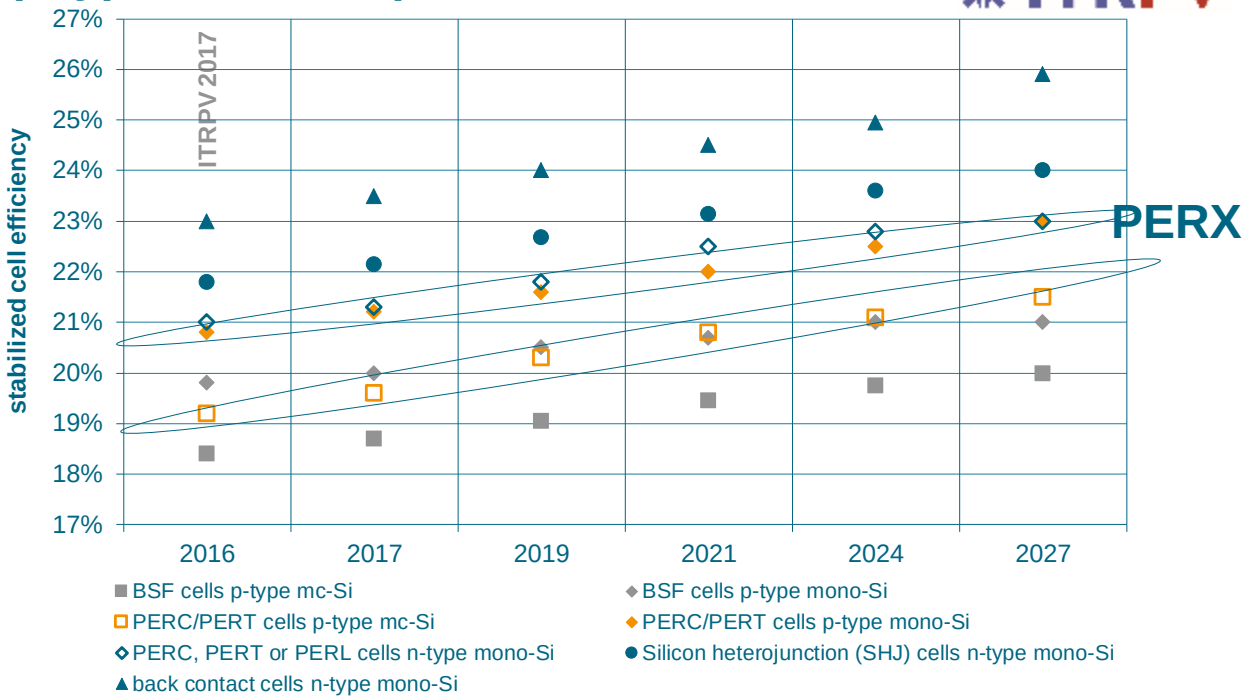
Cell – Products: cell technologies / cell efficiency trends

Trend: market share of cell concepts

2016: PERX ≈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 PERX is in production**

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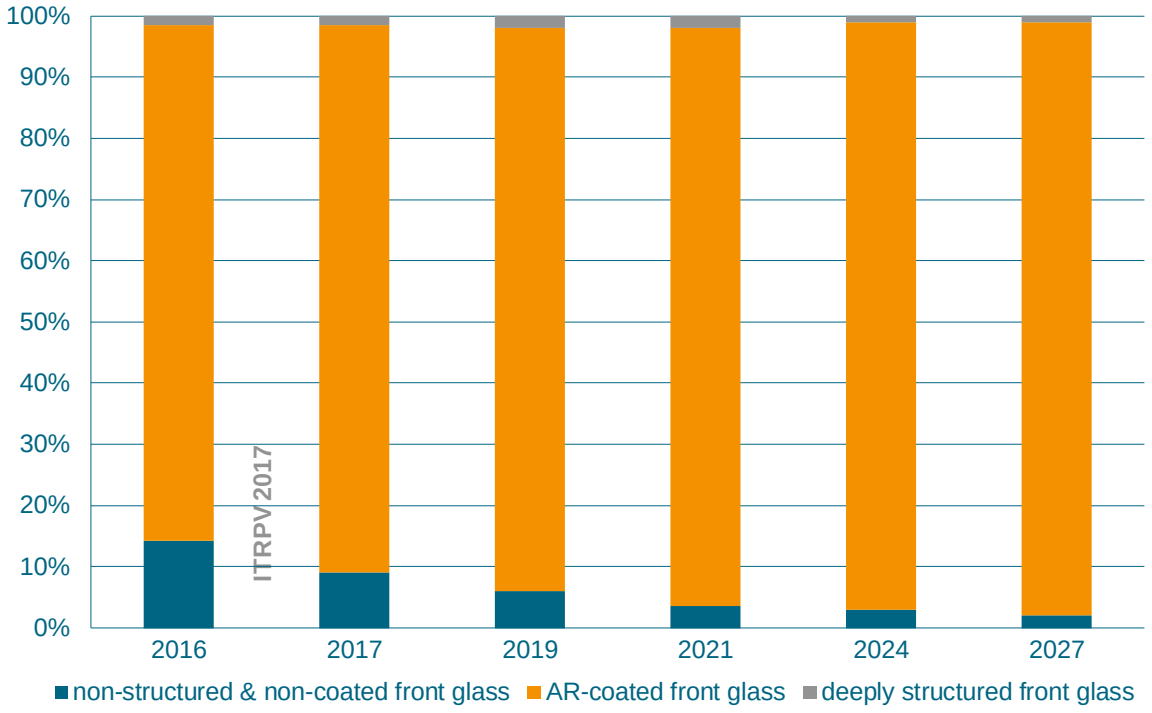
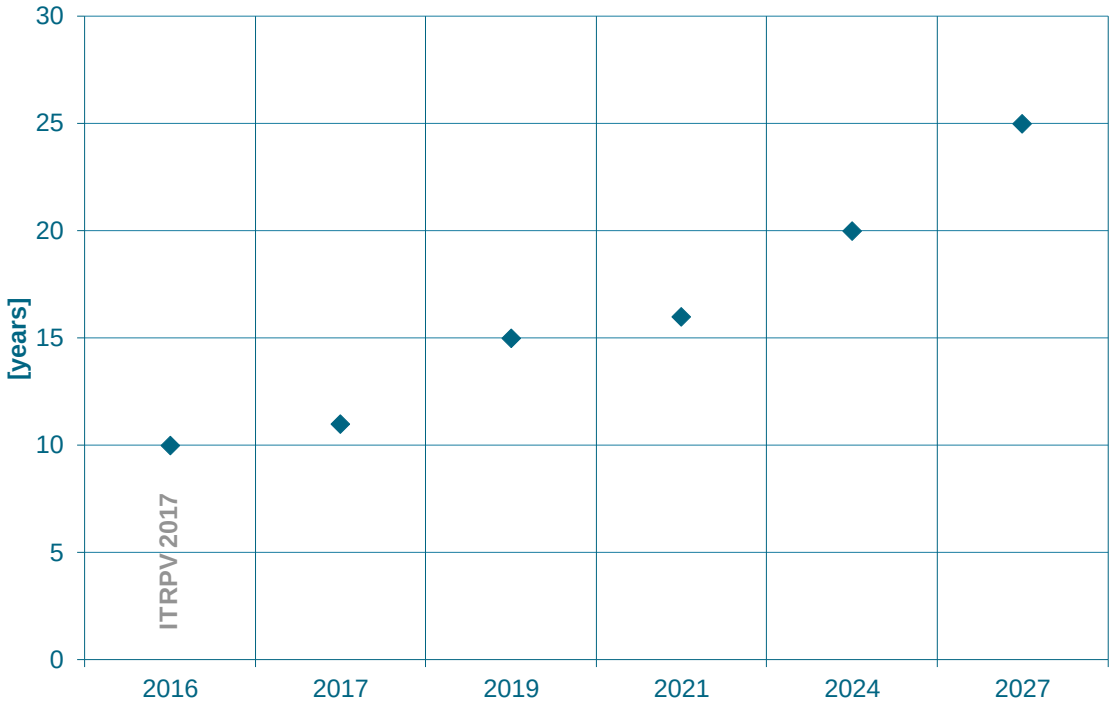
Module – Materials: front cover material

Trend: market share of front cover material



Trend: lifetime of AR coating

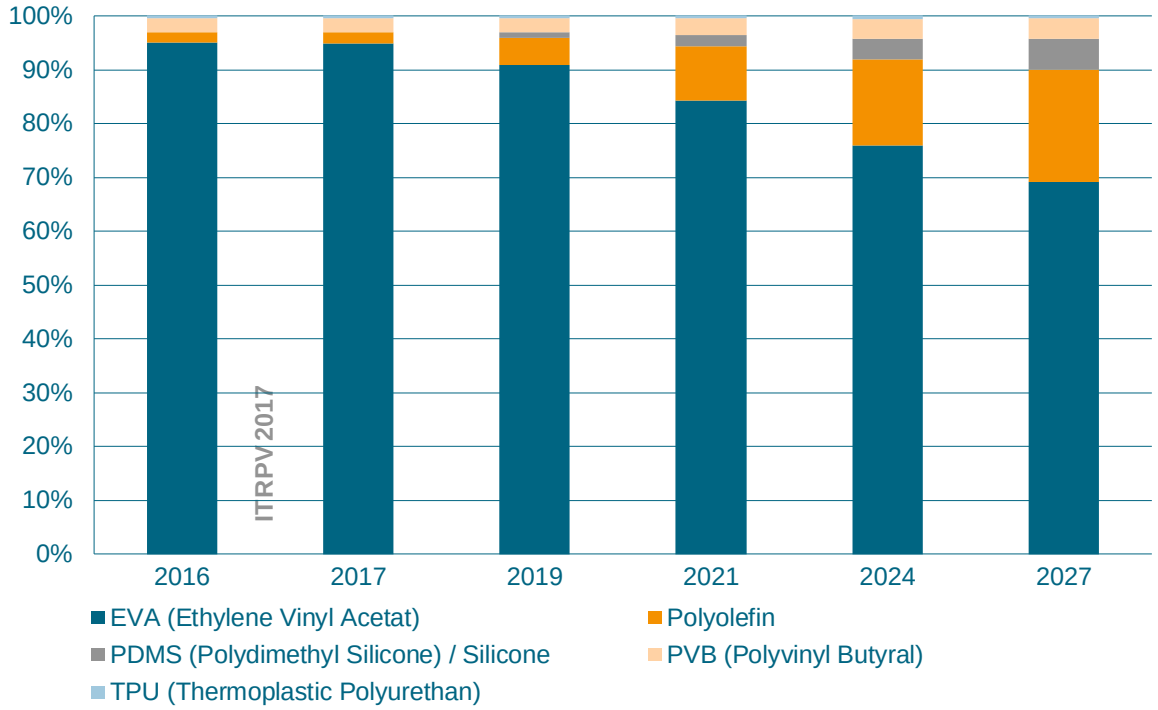


AR coated glass is mainstream

AR coating lifetime 10 years today will increase to 25 years

Module – Materials: foils

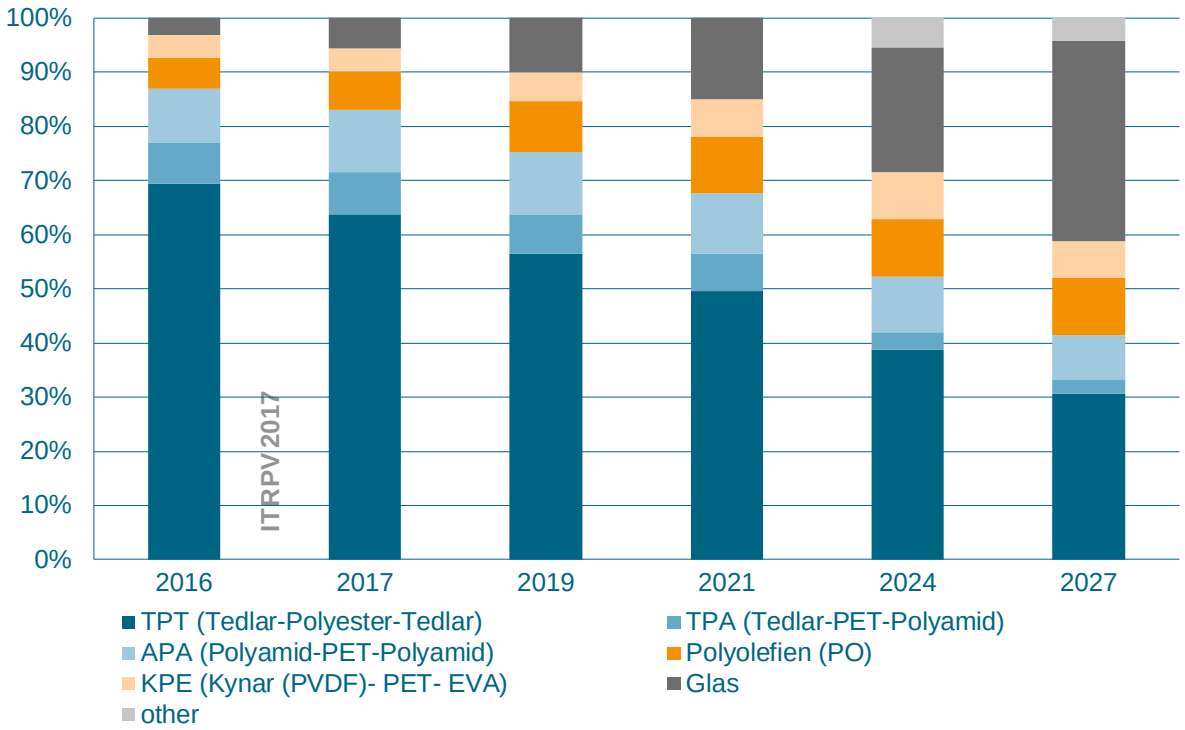
Trend: share of encapsulant materials



EVA is mainstream

Polyolefine will increase market share

Trend: share of back-sheet materials

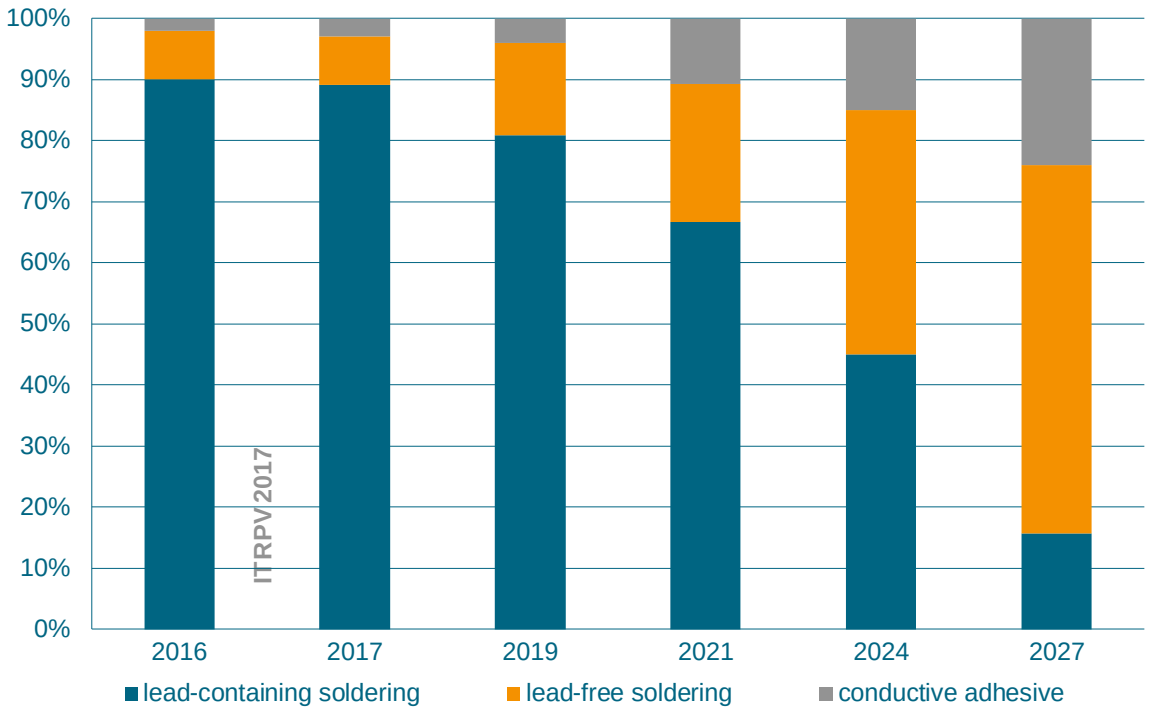


Glas will gain share as back cover material

TPT will lose share on the long run

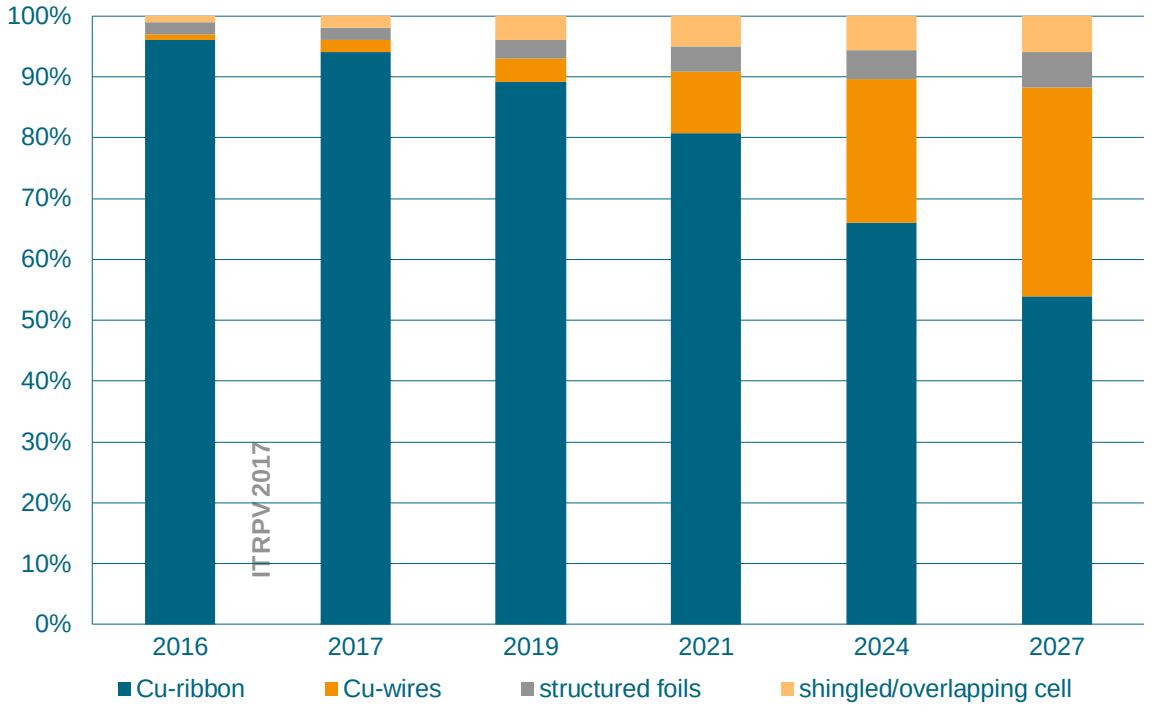
Module – Processes: interconnection technology

Trend: cell interconnection technology



Expanding market share:
lead free soldering + conductive adhesives

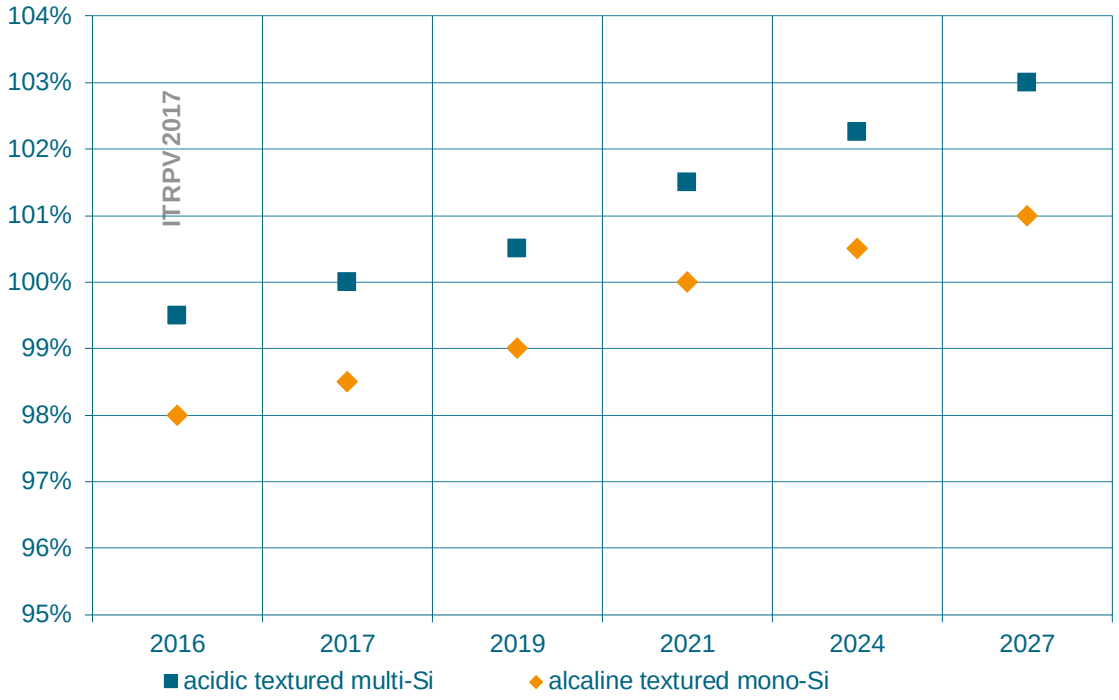
Trend: cell connection material



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

Module – Products: module power outlook

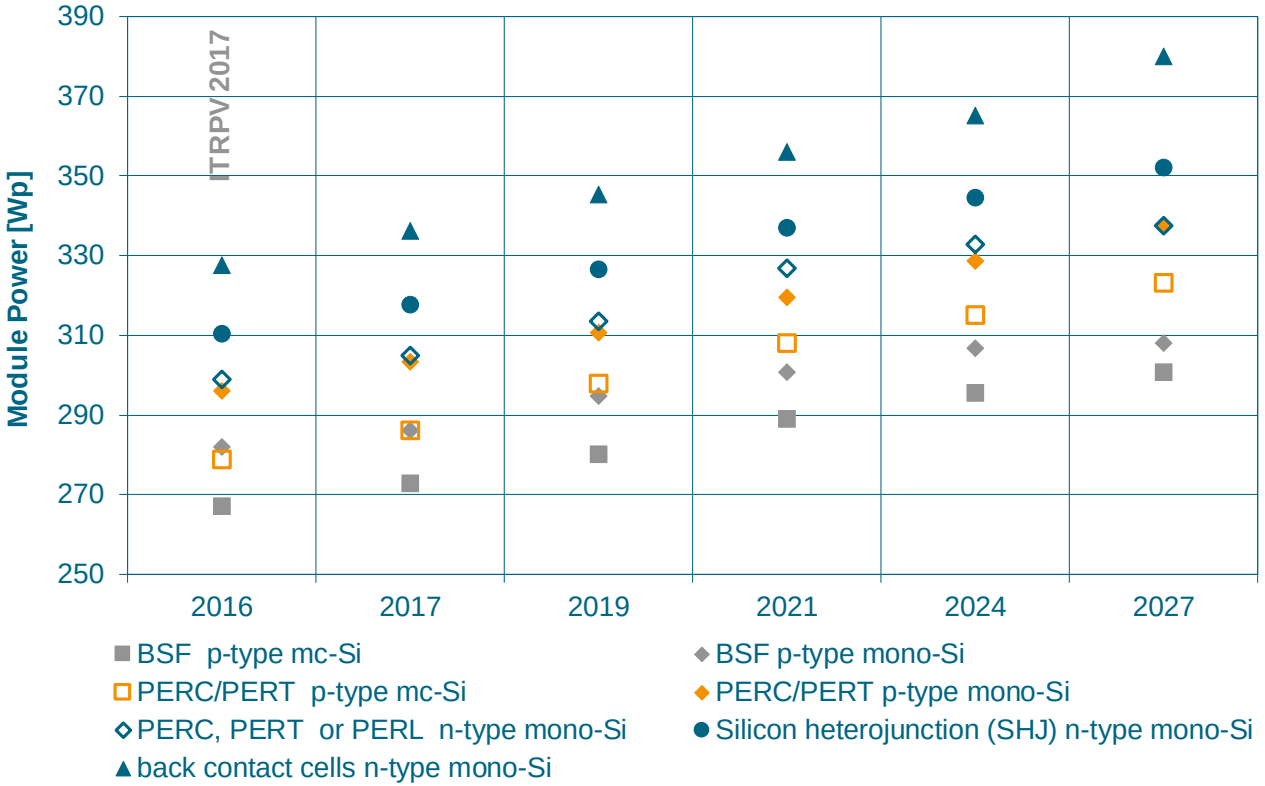
Trend: cell to module power ratio (CTM)



CTM will increase to > 100%

→ Acidic texturing has higher CTM

Trend: module power of 60 cell (156x156mm²)



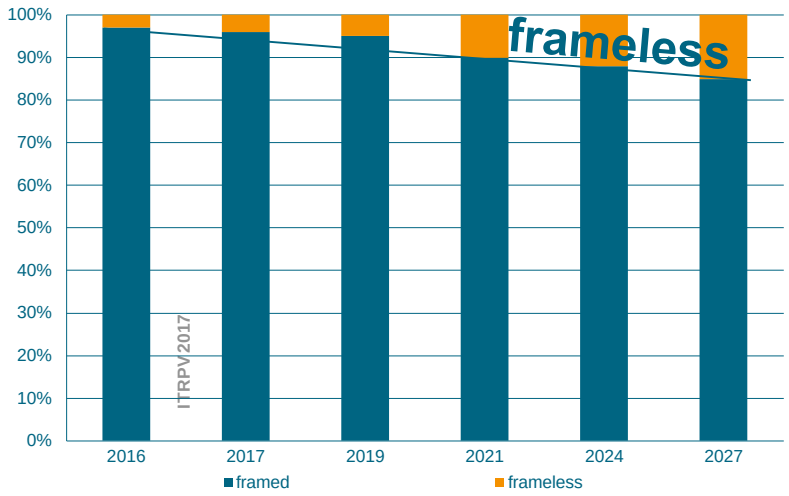
60 cell modules 2017:

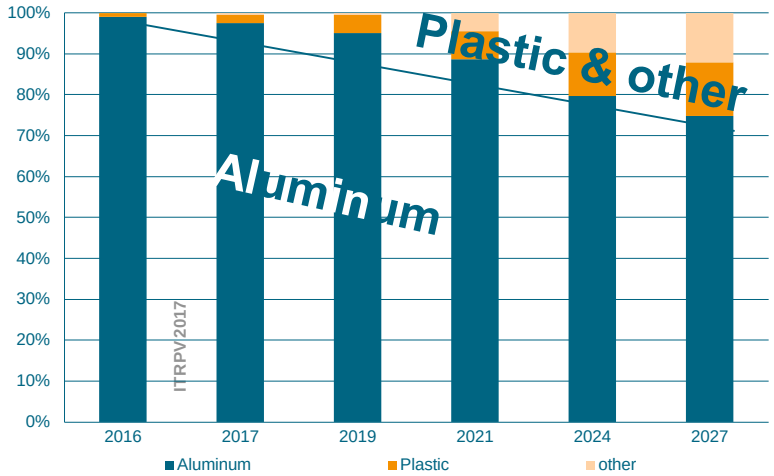
Mono p-type PERX: 300 W are standard

Multi p-type PERX: 285 W are common

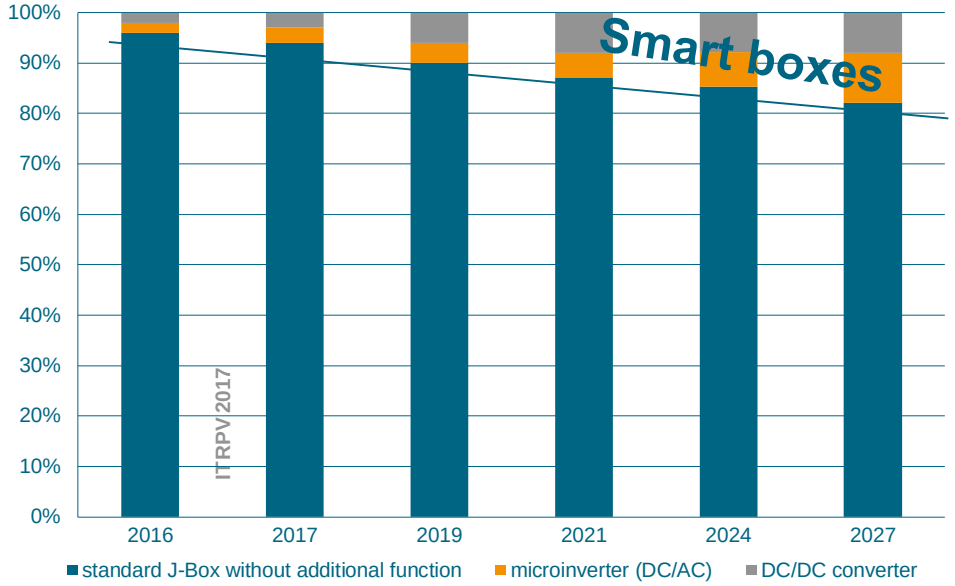
Module – Products: framed modules and J-Boxes

Trend: share of frameless c-Si modules





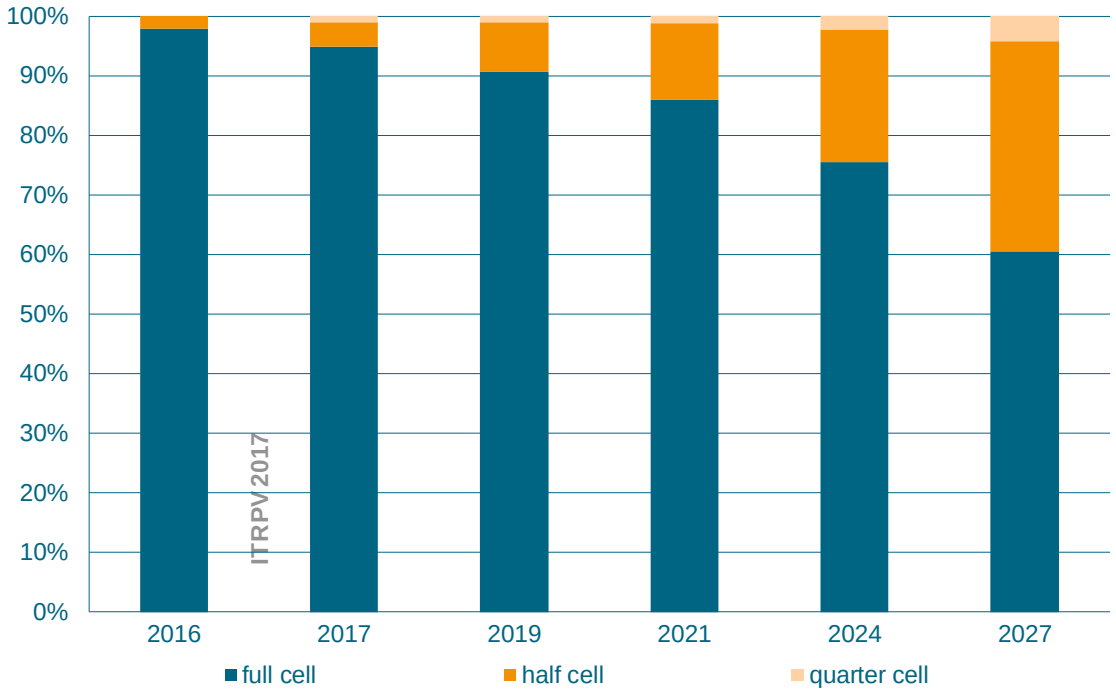
Trend: share of smart J-Boxes



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

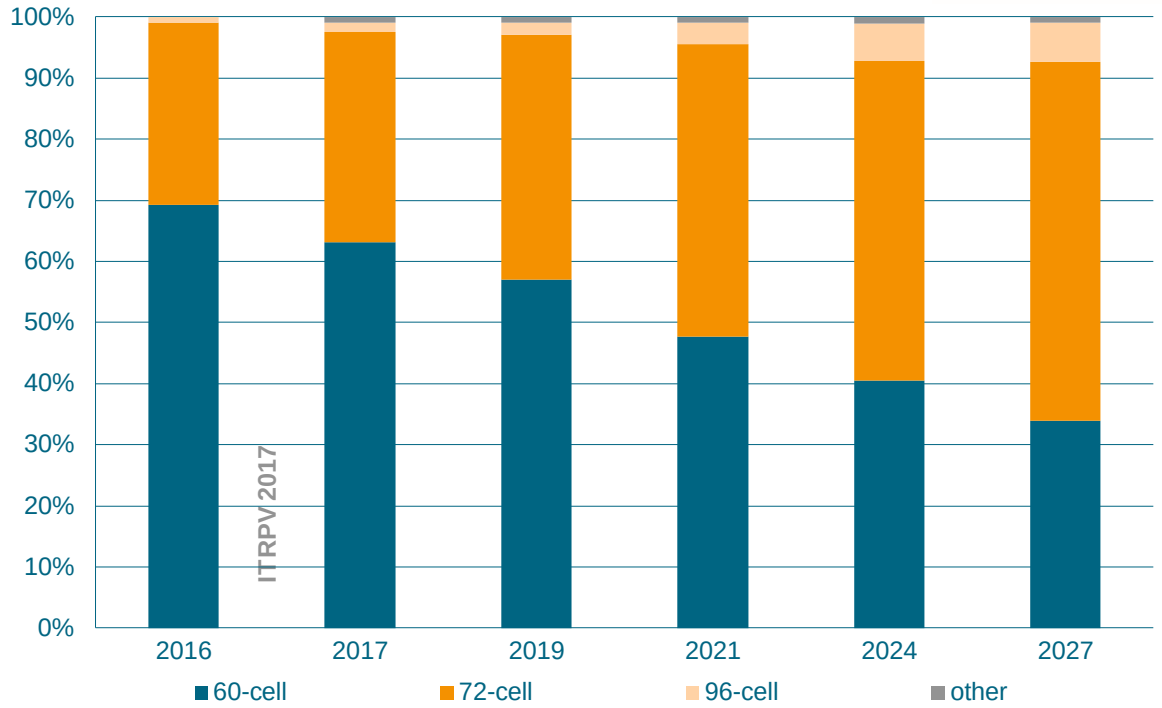
Module – Products: module size

Trend: share of cell dimensions



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

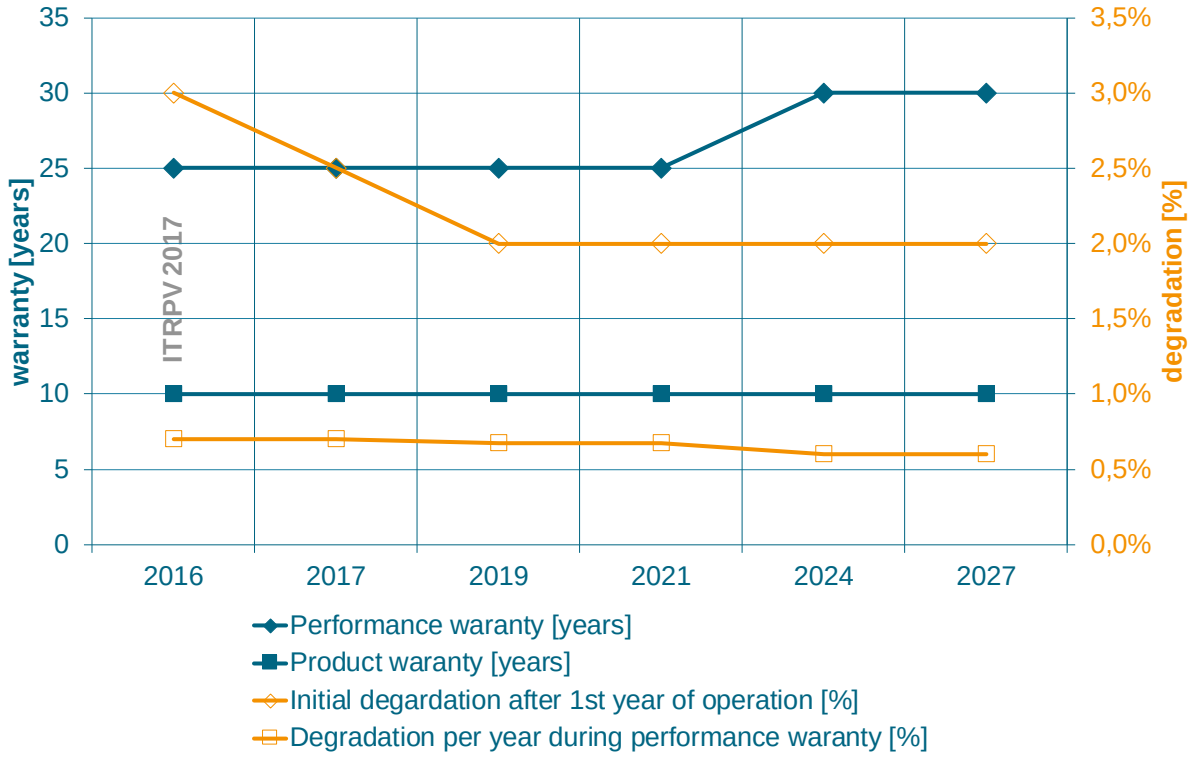
Trend: share of module size (full cell)



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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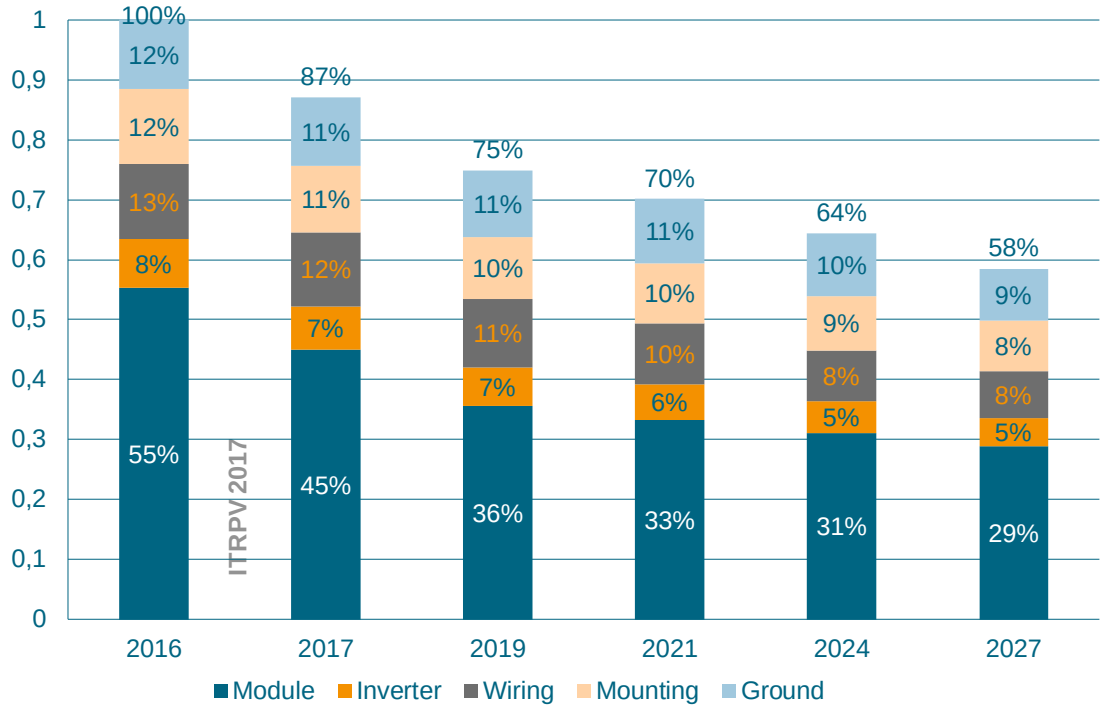
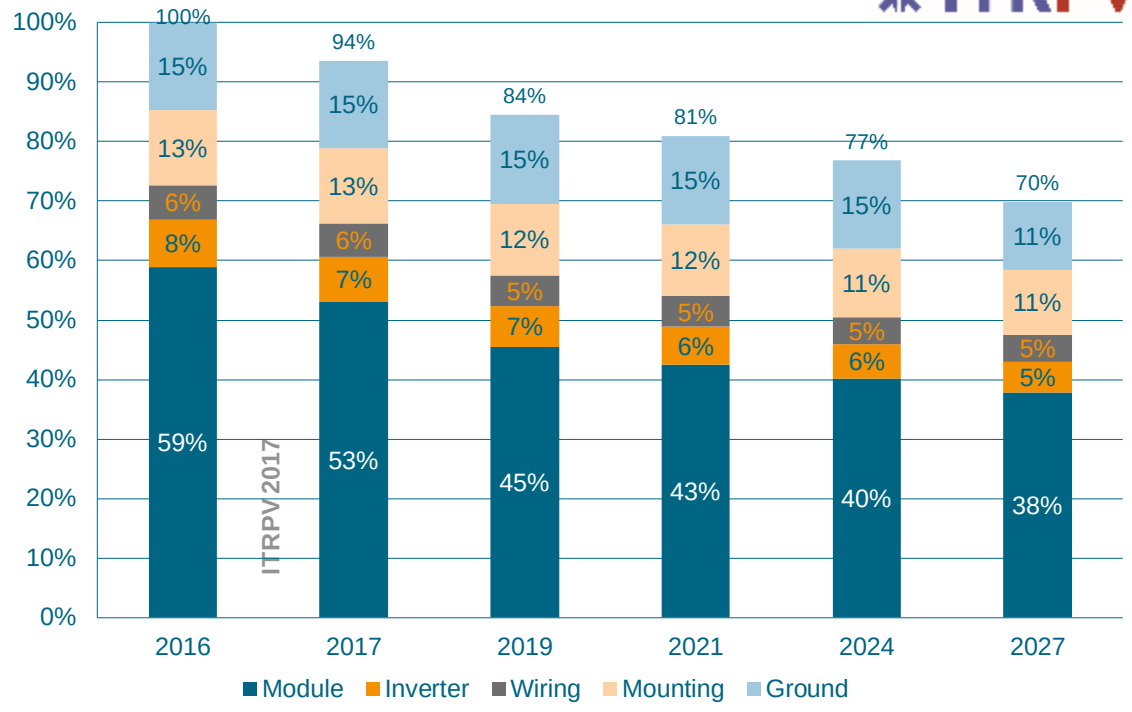
   - Module - Materials, Processes, Products
   - **Systems**
4. Summary and Outlook

Systems – Balance of system (BOS) for power plants

Trend: BOS in Europe and US



Trend: BOS in Asia

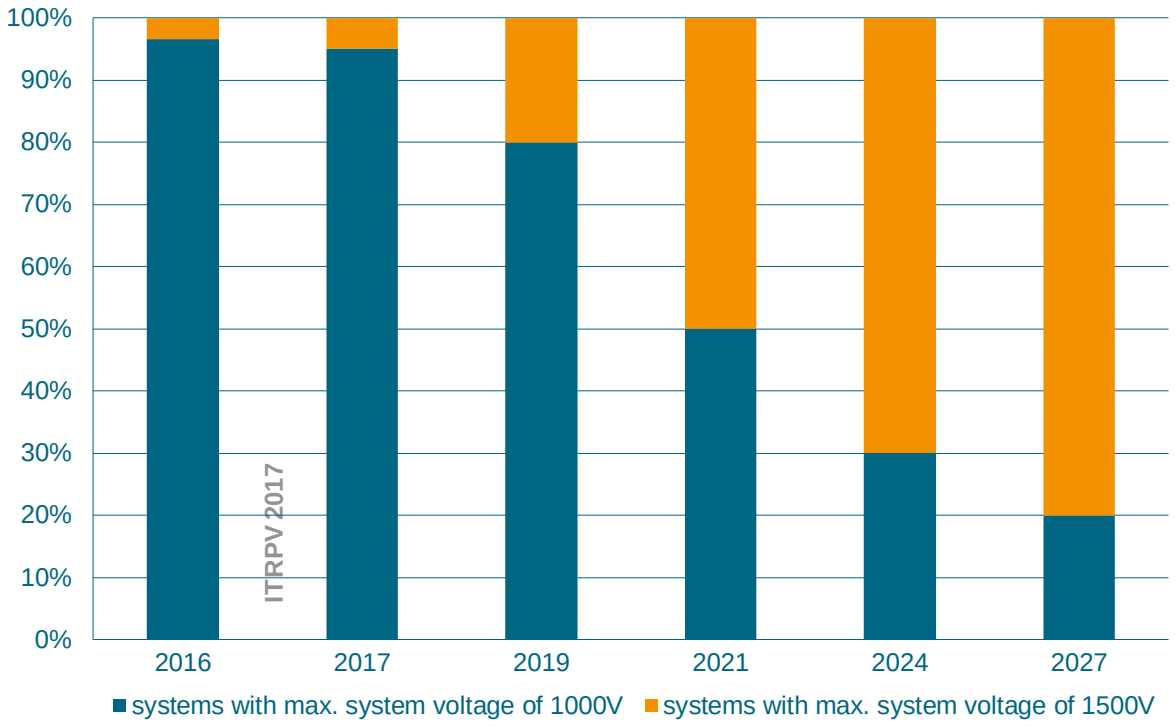


Still significant cost reductions foreseen

Costs in Asia are assumed to be significant lower

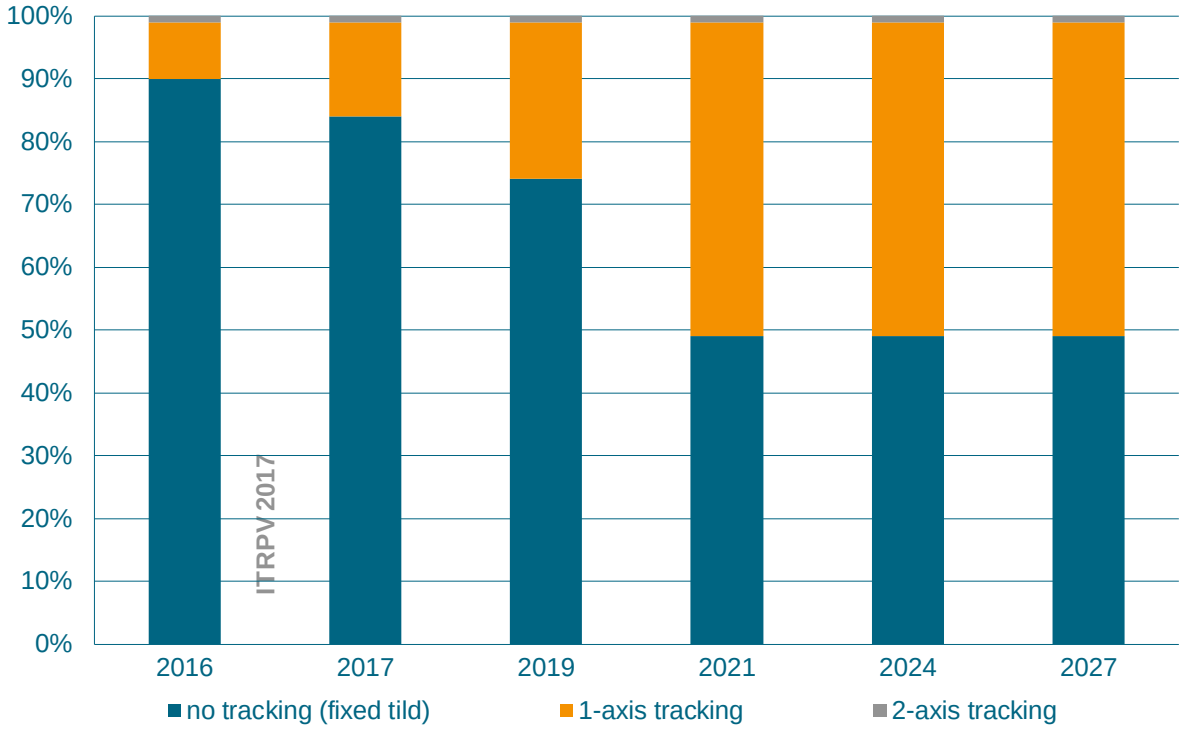
Sstems – Components: system voltage /tracking

Trend: system voltage



1500V are the future

Trend: tracker systems in power plant applications



1-axis trackers will gain market share

Systems – Components: module power classes

Trend: module peak power for PV power plants > 100kW (PP)

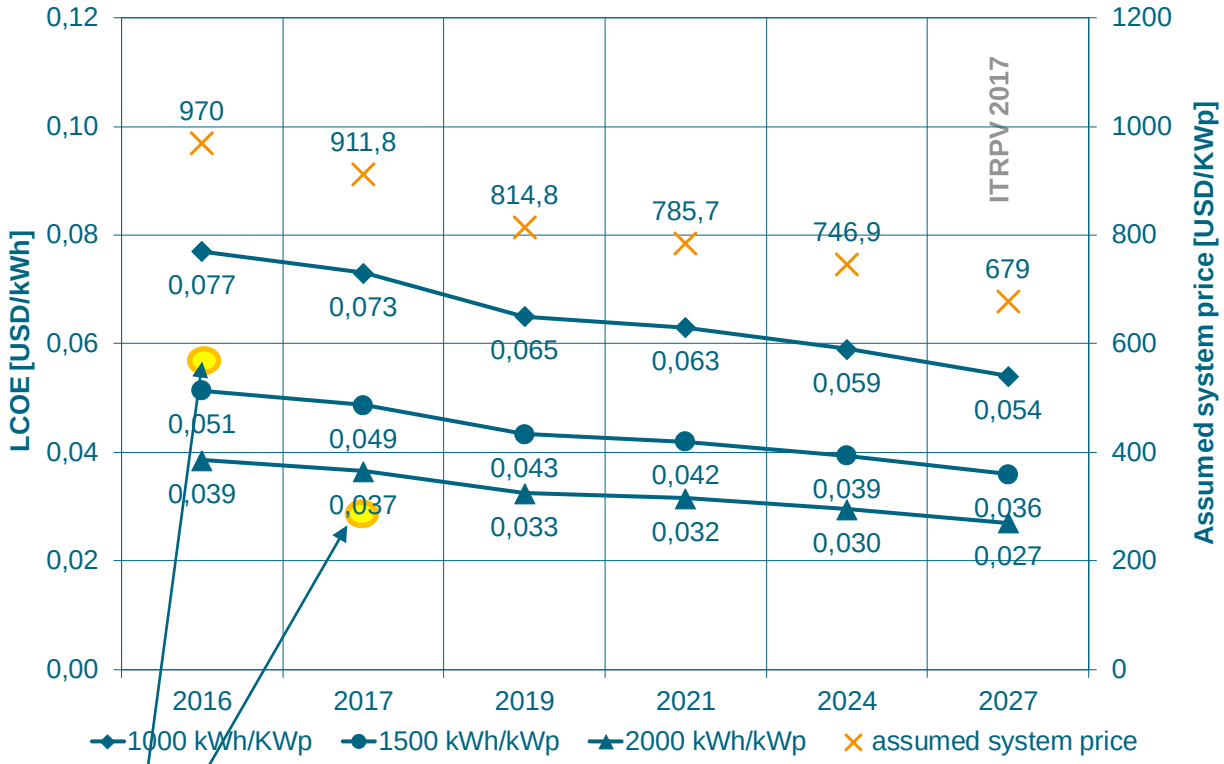
Module power for PV plants will increase

60 cells:	**270 …. 310 Wp**
72 cells:	**320 …. 380 Wp**

→ mc-Si considered as main stream for PPs

Systems – Levelized Cost of Electricity (LCoE)

Trend: LCoE progress – a minimum approach



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

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

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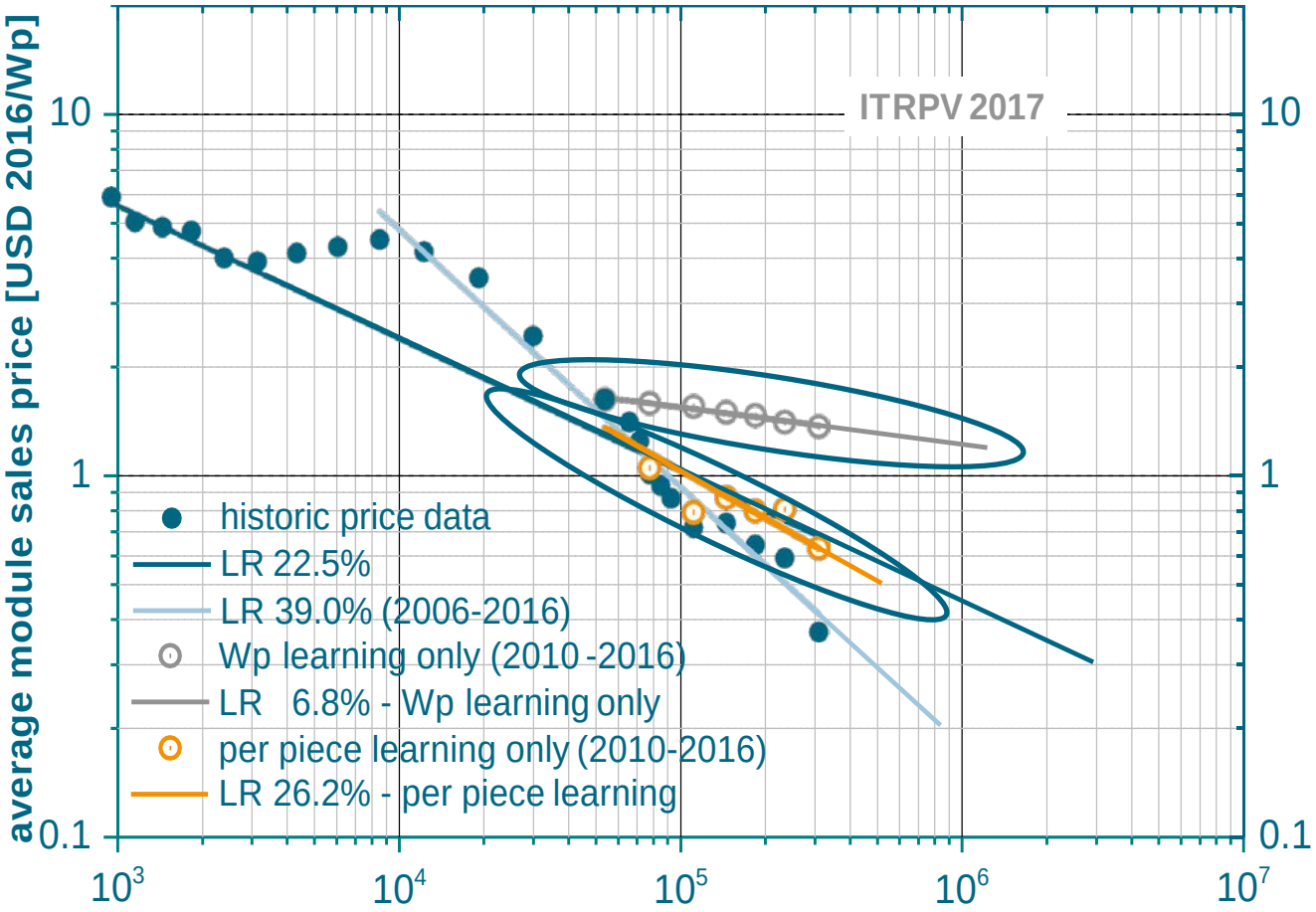
4. **Summary and Outlook**

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:

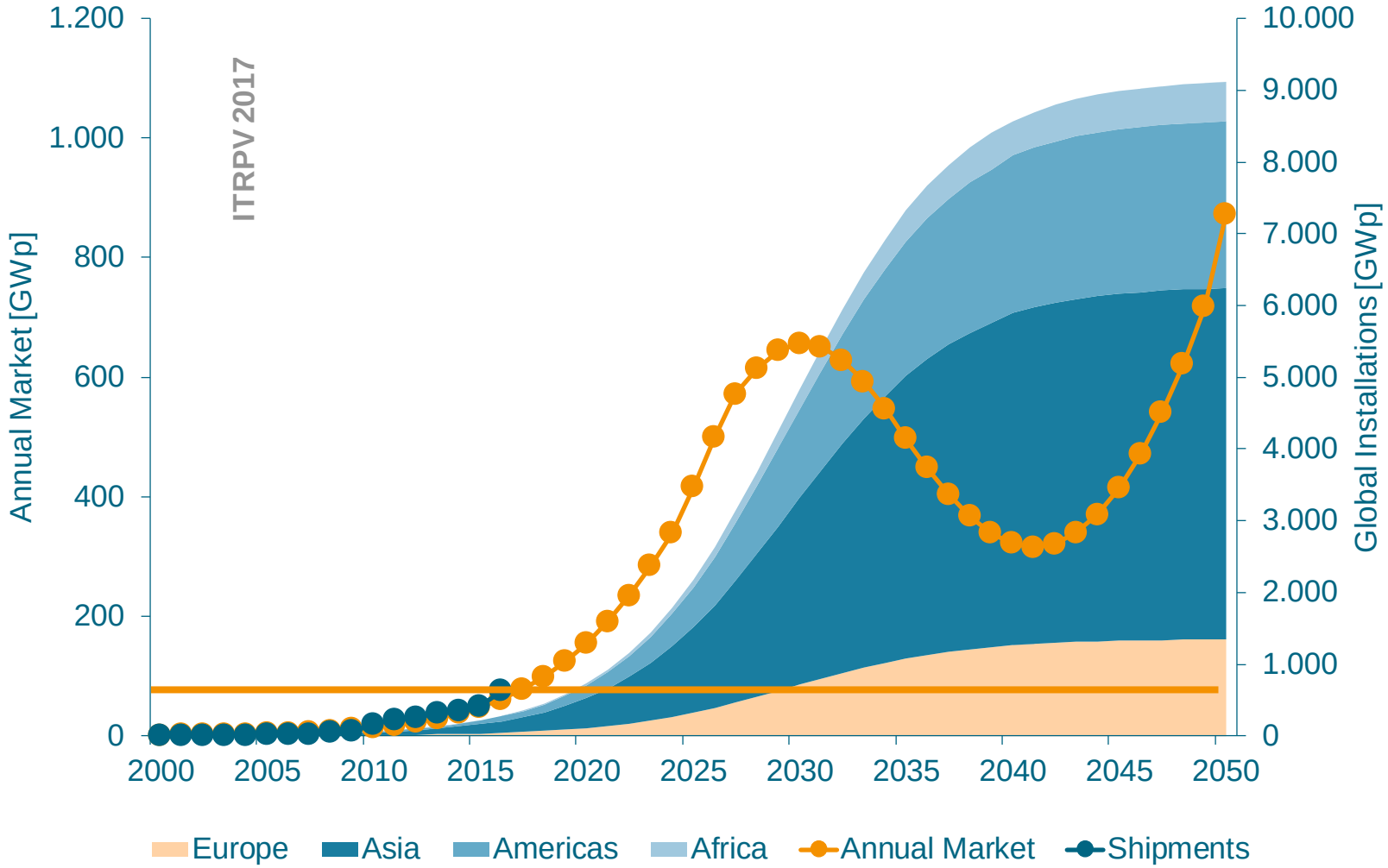
efficiency increase
+ continues cost reduction per piece
= cost reduction of PV generated electricity

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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