



Australian Centre for Advanced Photovoltaics

“2015 SEMI Roadmap for Photovoltaics: What's Hot and What's Not?”

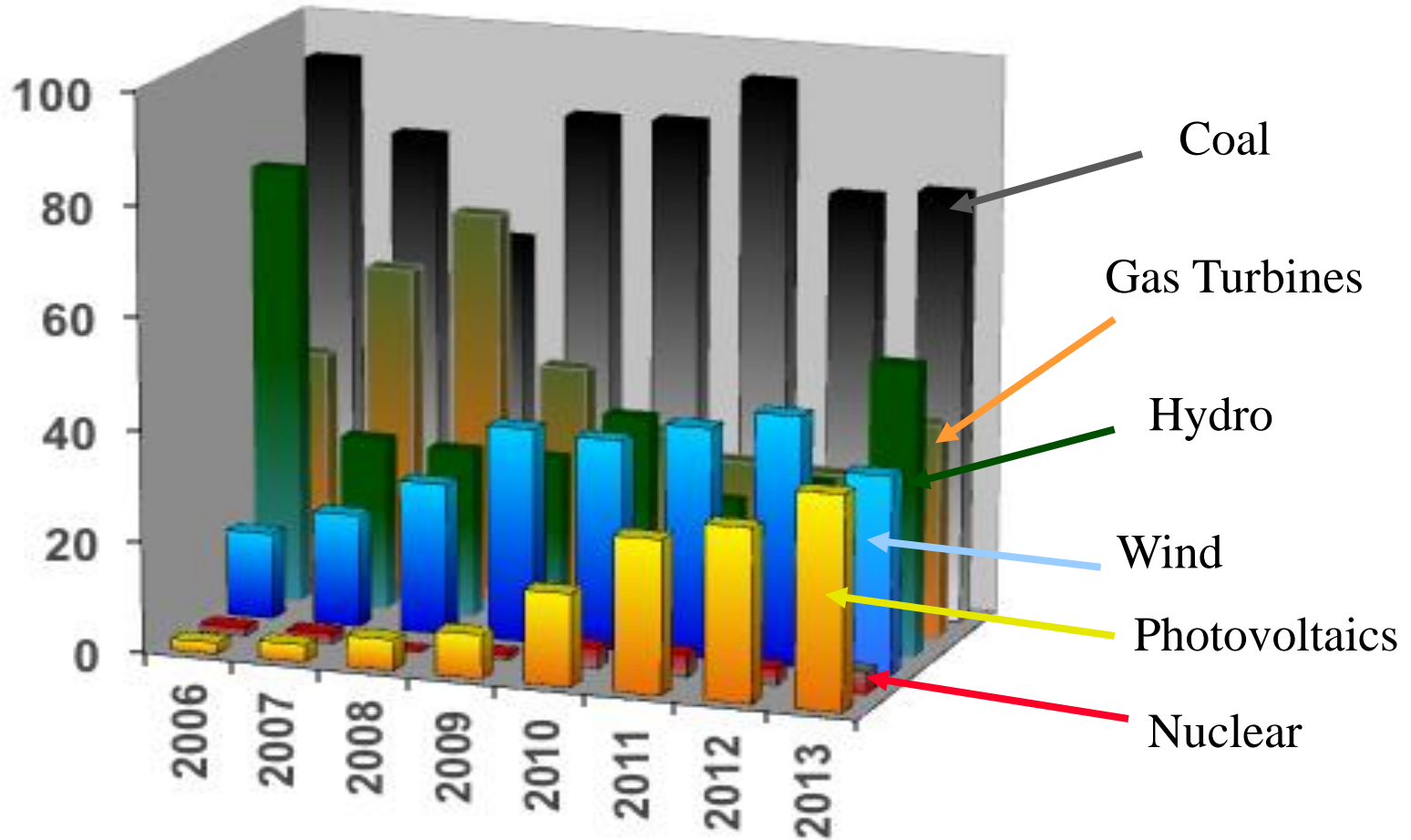
**Martin A. Green,
UNSW Australia**





Annual capacity increase

New Capacity, GW



EPVIA, IAEA, GWEA, Bloomberg

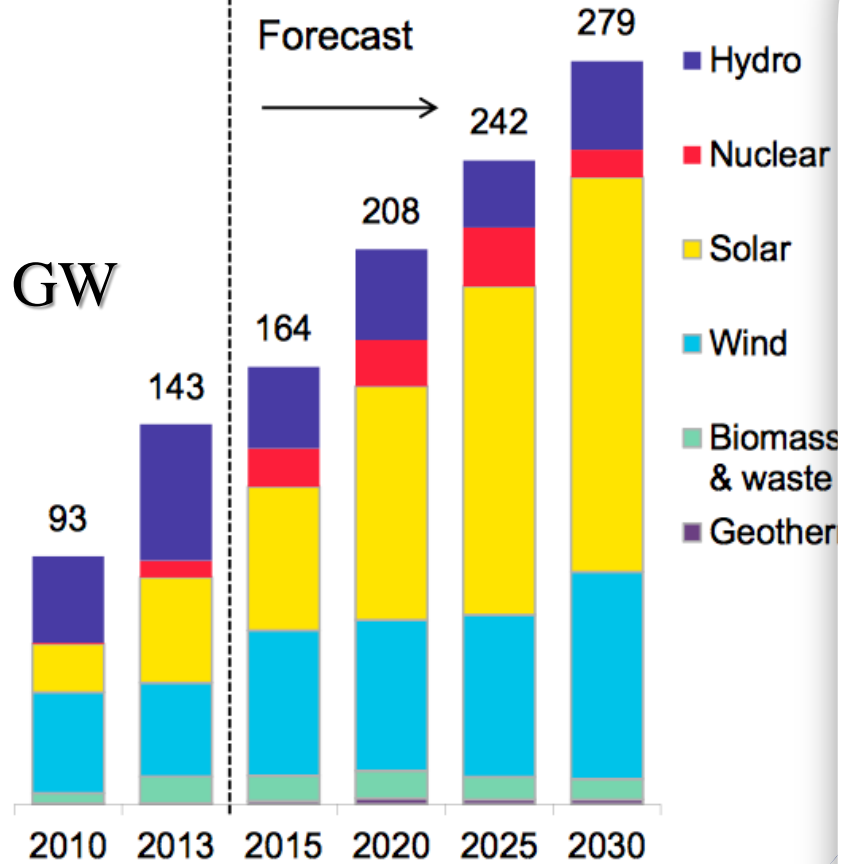




ACAP

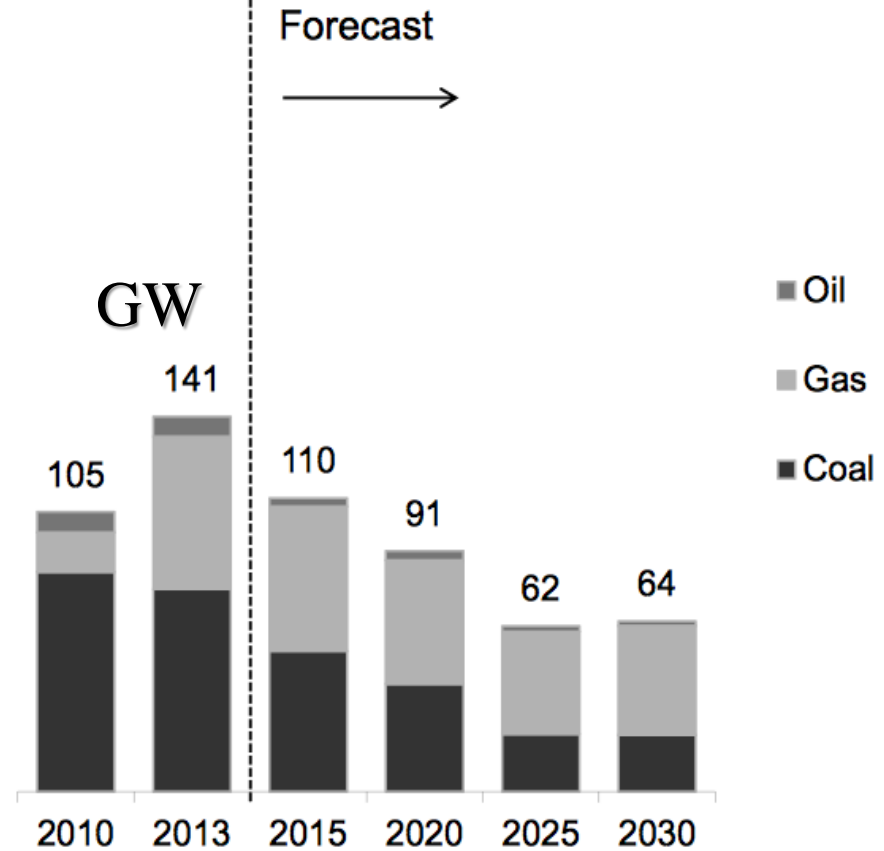
Annual capacity increase (Bloomberg April 2015)

CLEAN ENERGY



Source: Bloomberg New E

FOSSIL FUEL



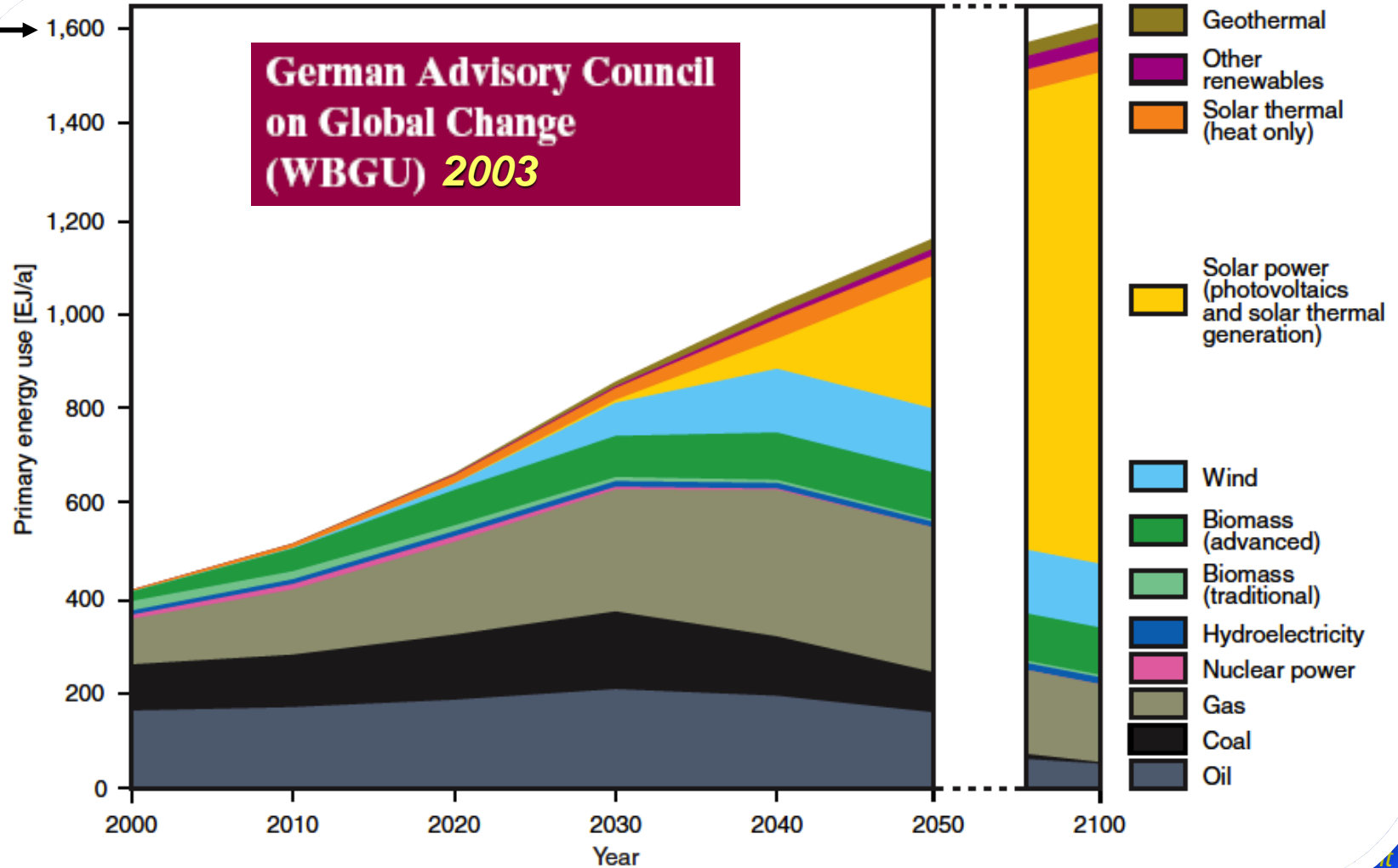
Note: Underlying data is from GREMO 2014



ACAP

Power source for the future?

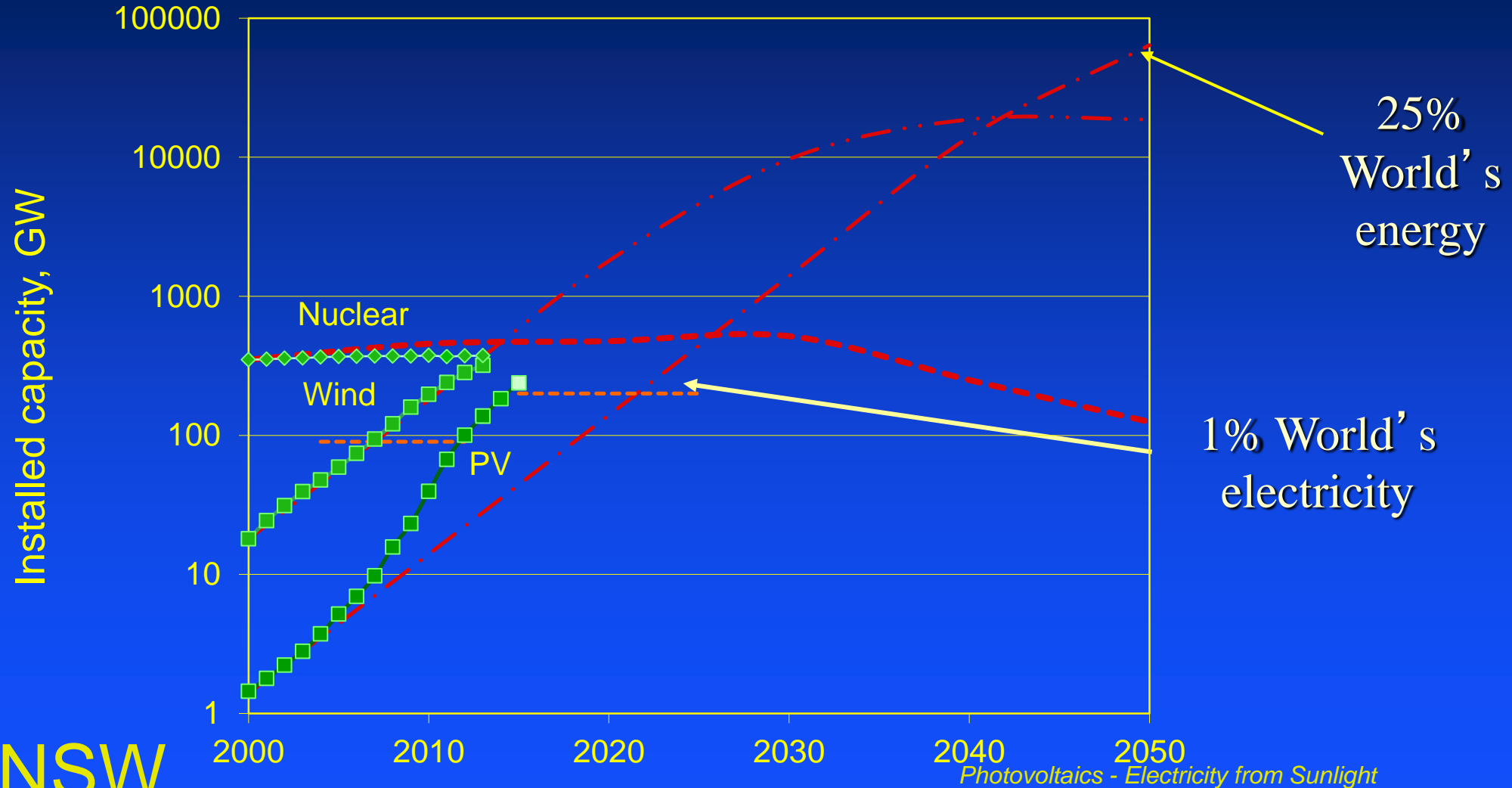
50.7 Terawatt





ACAP

“Submerged” progress



UNSW



International Technology Roadmap for Photovoltaic



International Technology Roadmap for Photovoltaic (ITRPV)

2014 Results

April 2015

Supported by:



Semi ITRPV 2015 Roadmap

Photovoltaics - Electricity from Sunlight

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* Co-chair of the ITRPV working group

Silicon processing



Poly Silicon Casting



Multi-Crystalline Silicon Ingot



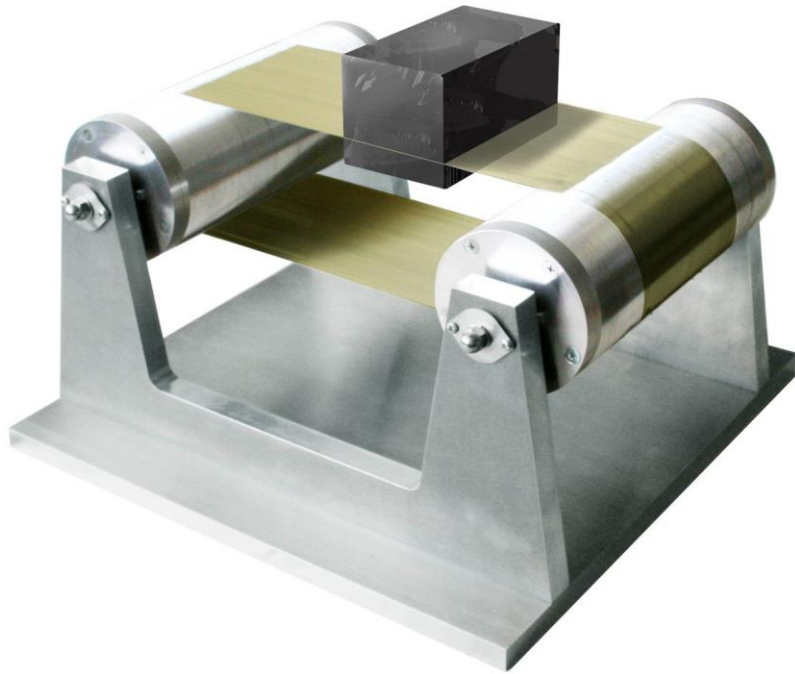
Blocking Silicon



Silicon Brick



Silicon processing



Multi-Crystalline Silicon Ingot



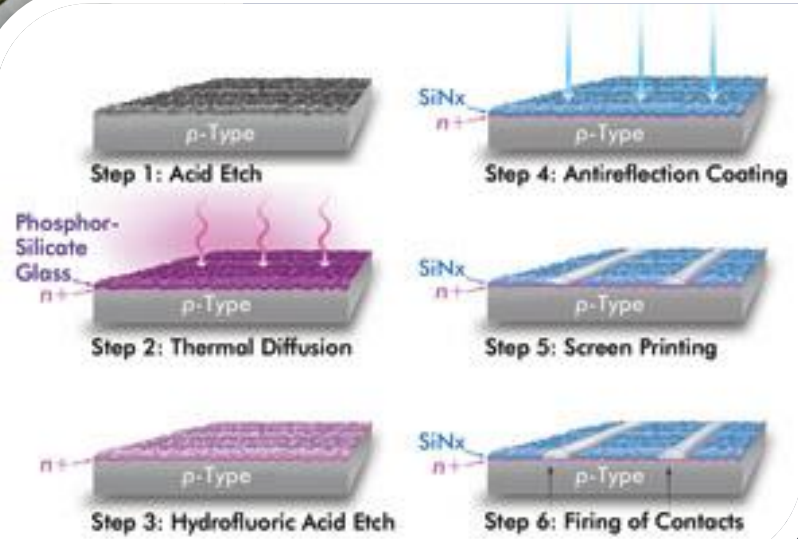
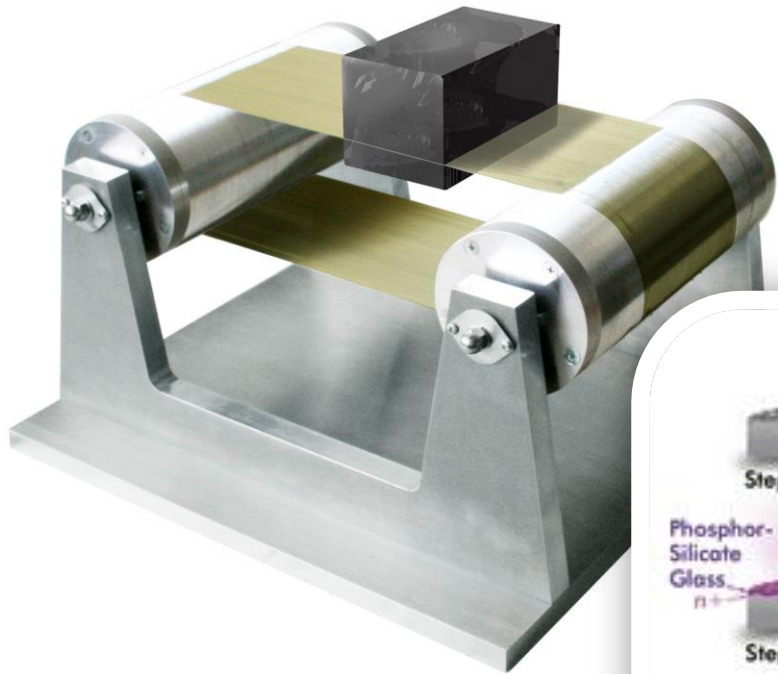
Blocking Silicon



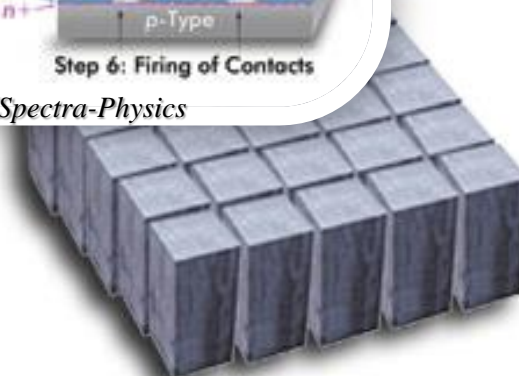
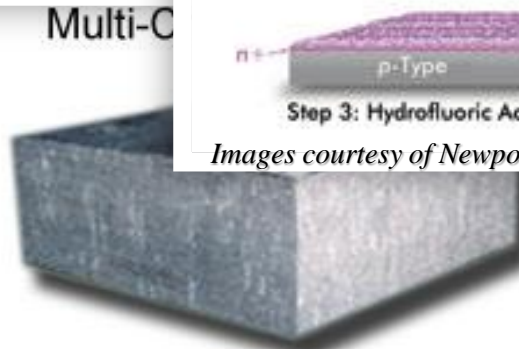
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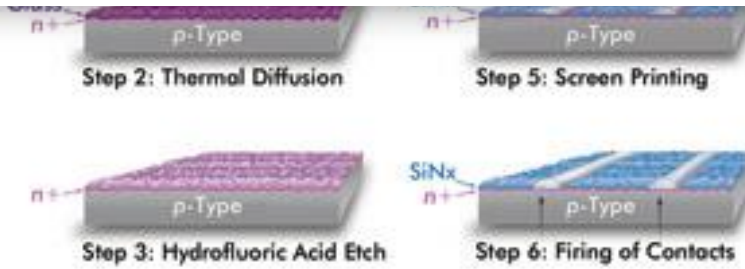
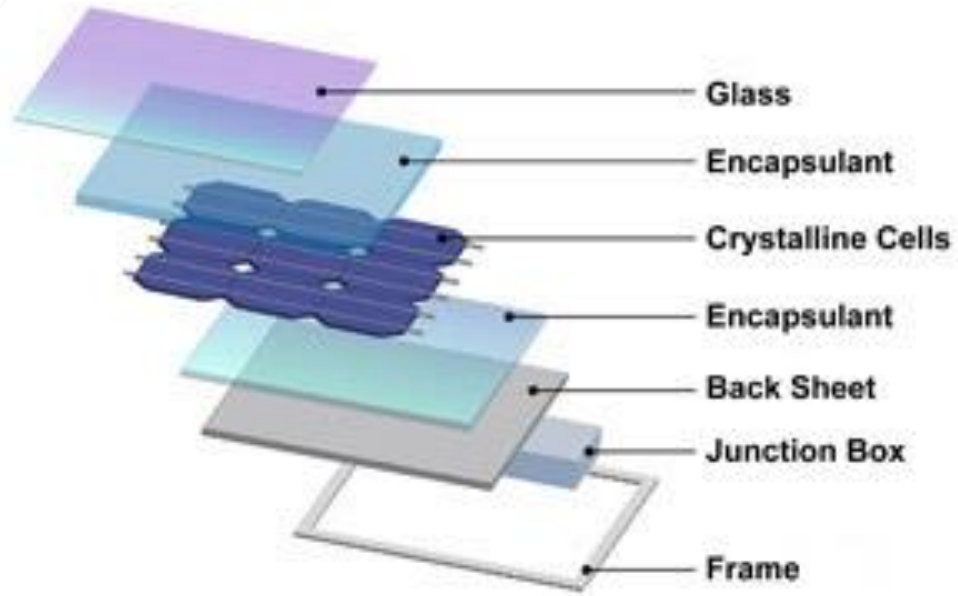
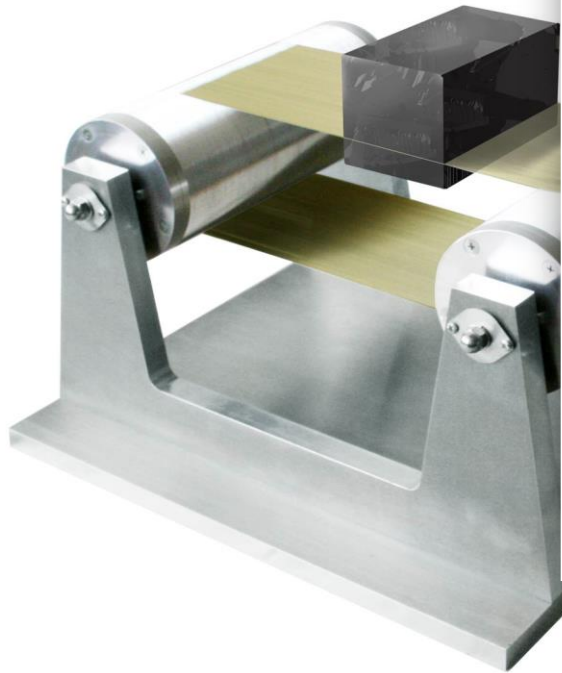
Silicon processing



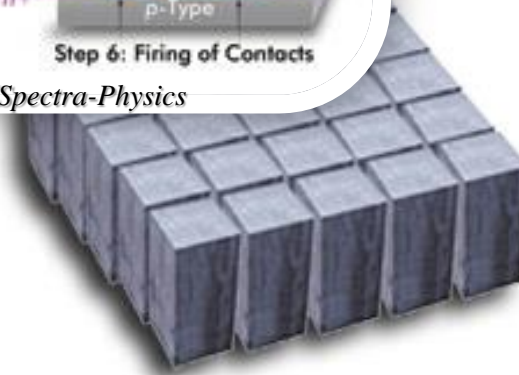
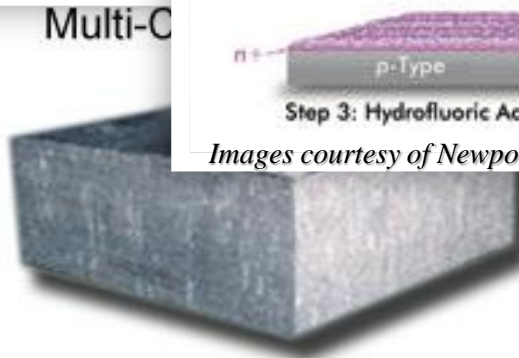
Images courtesy of Newport Corp./Spectra-Physics



Silicon Brick

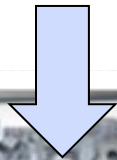
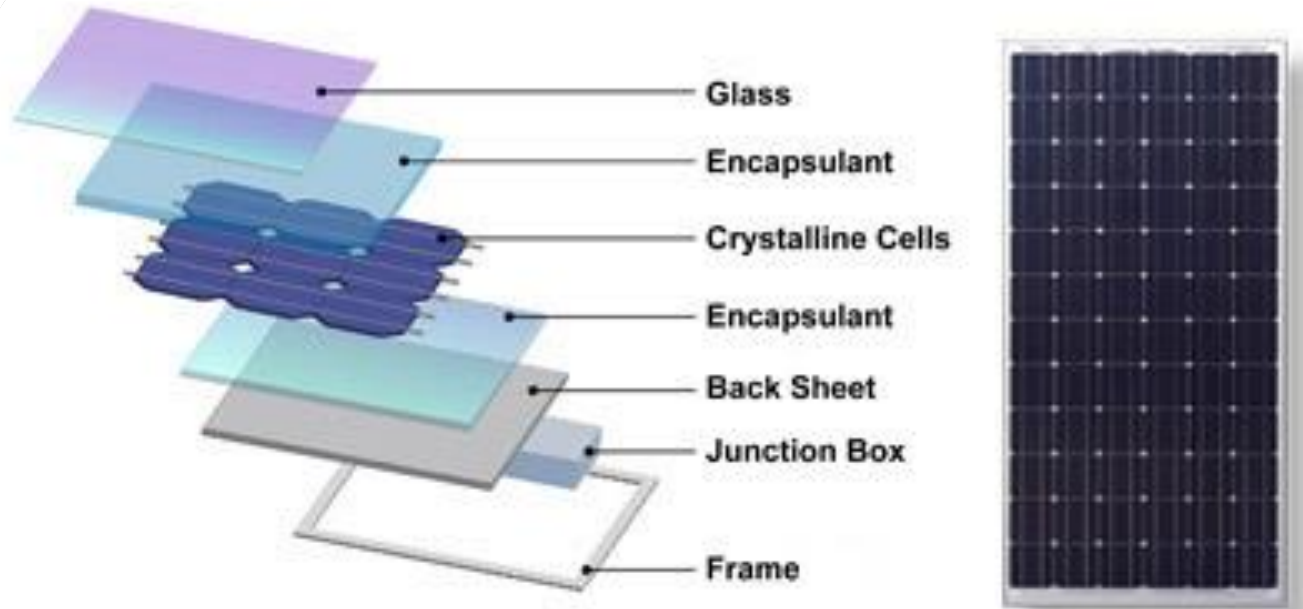
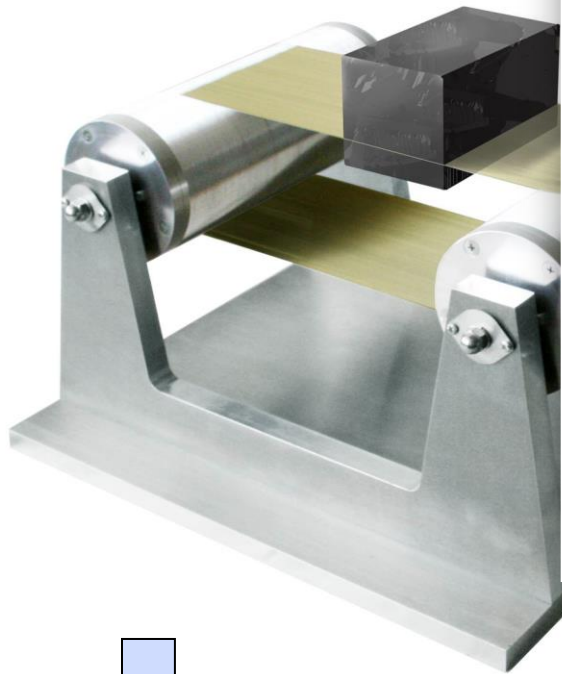


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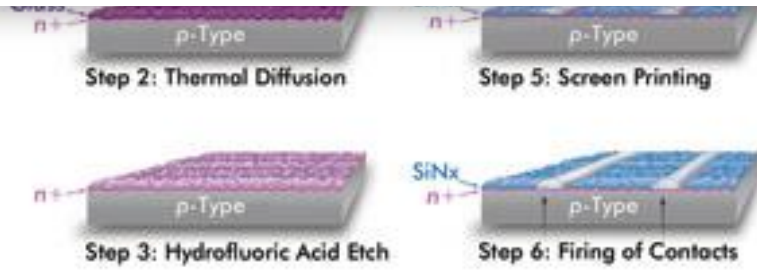


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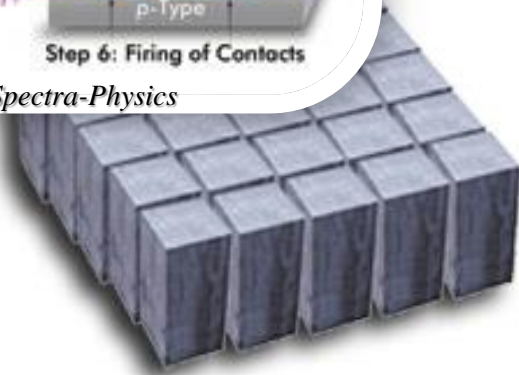


Multi-C



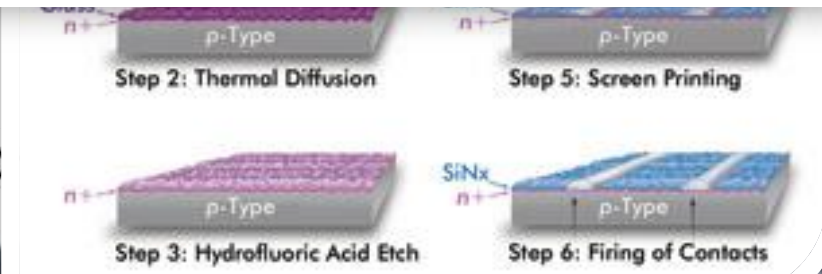
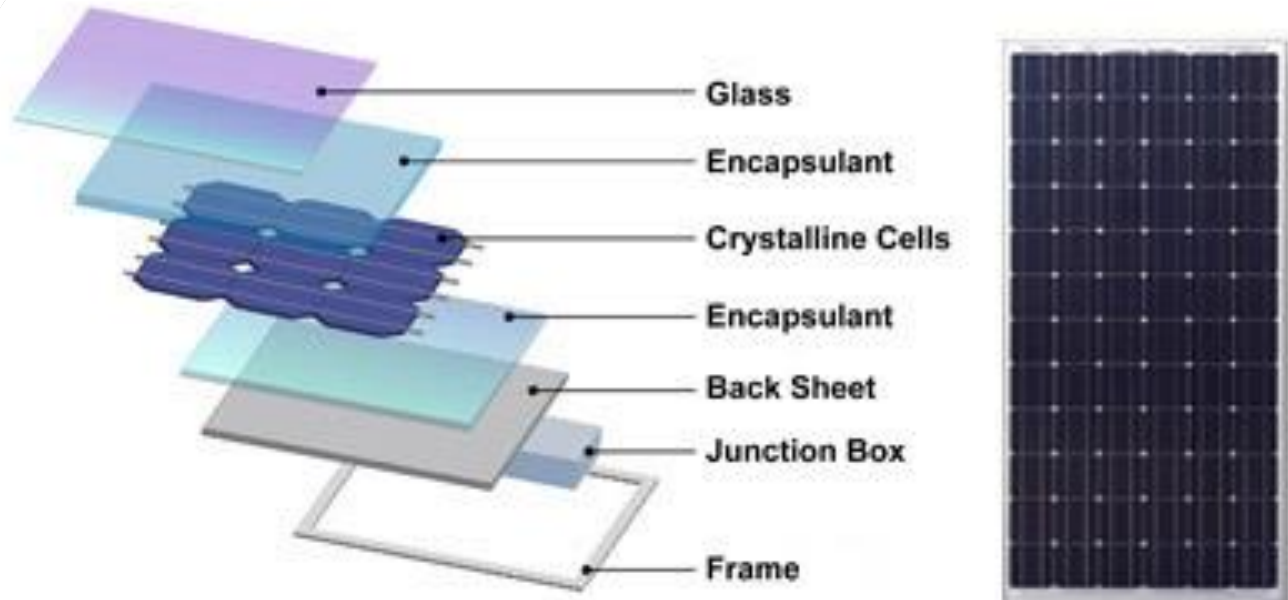
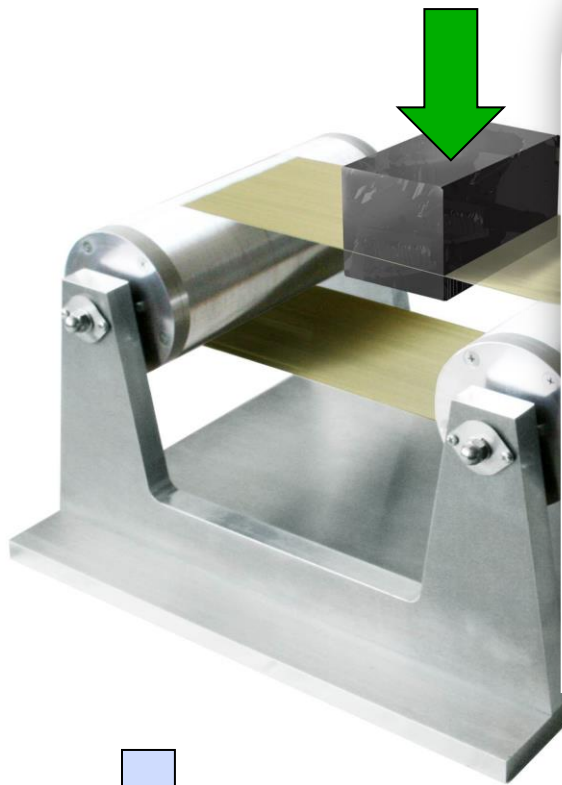
Images courtesy of Newport Corp./Spectra-Physics

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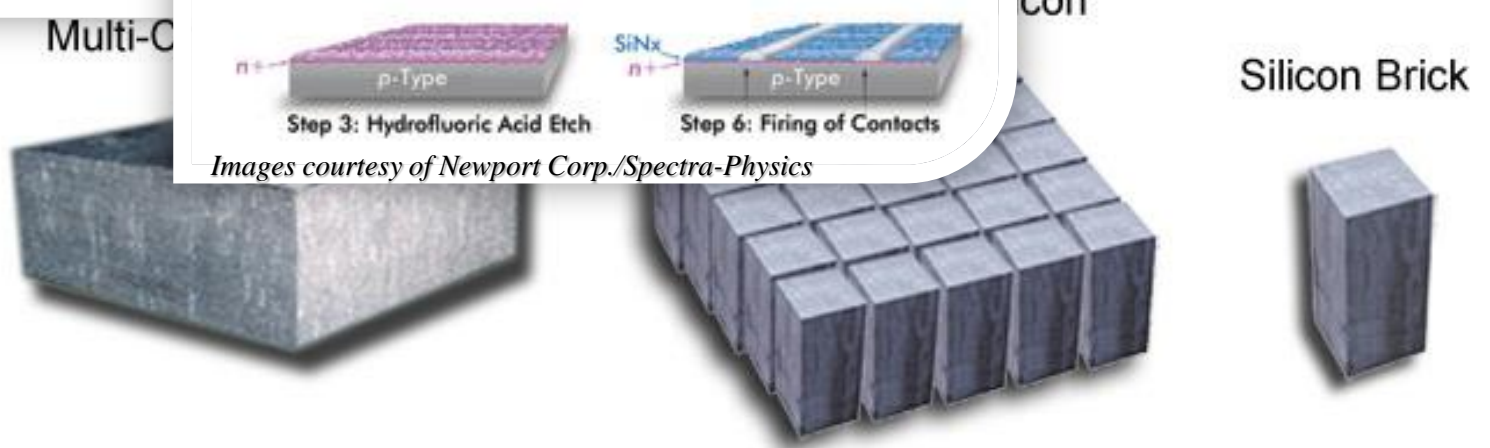


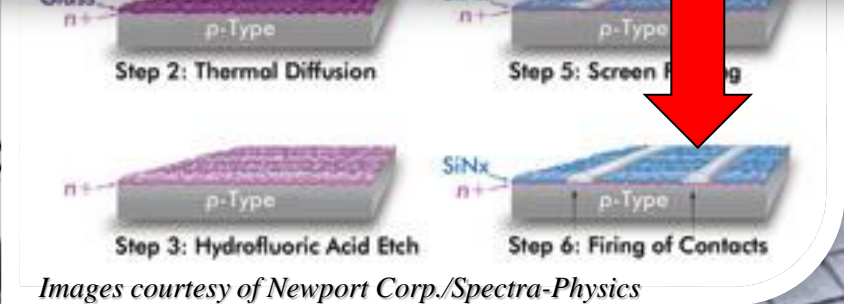
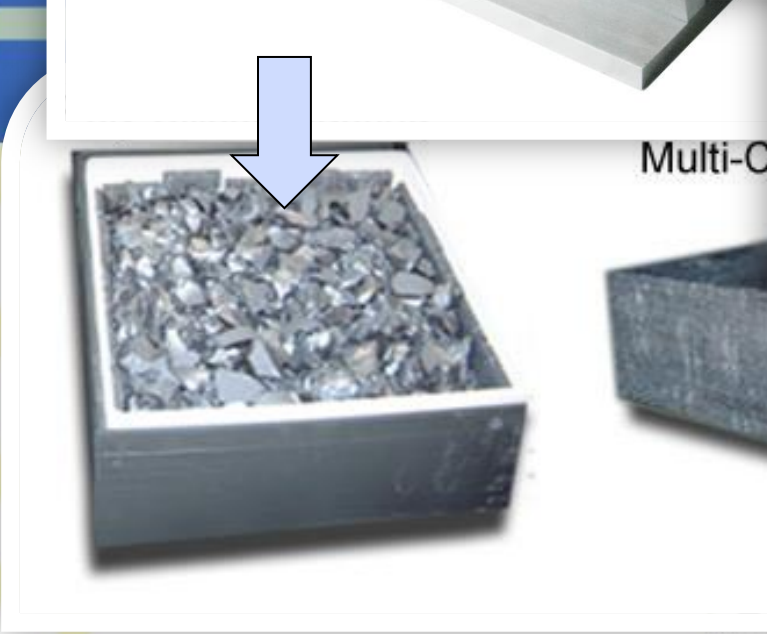
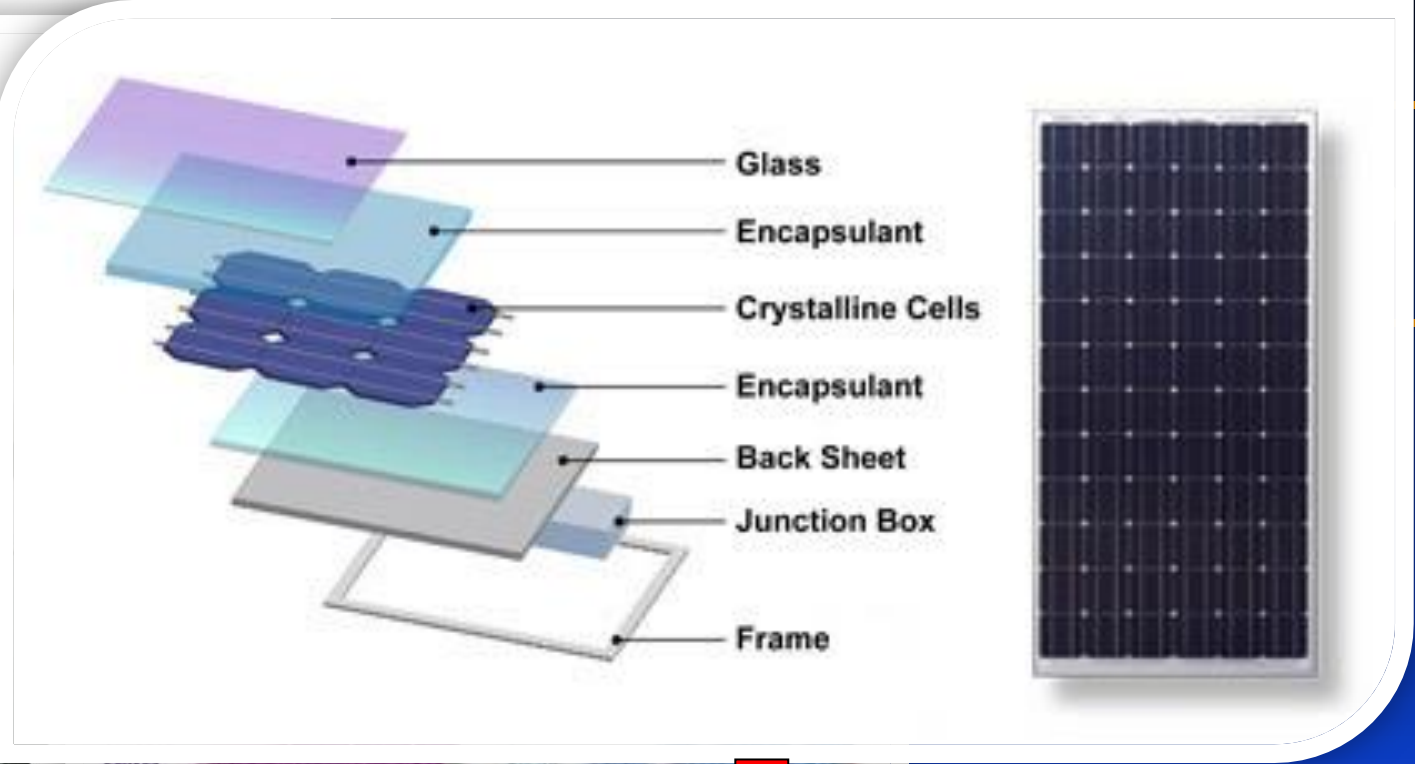
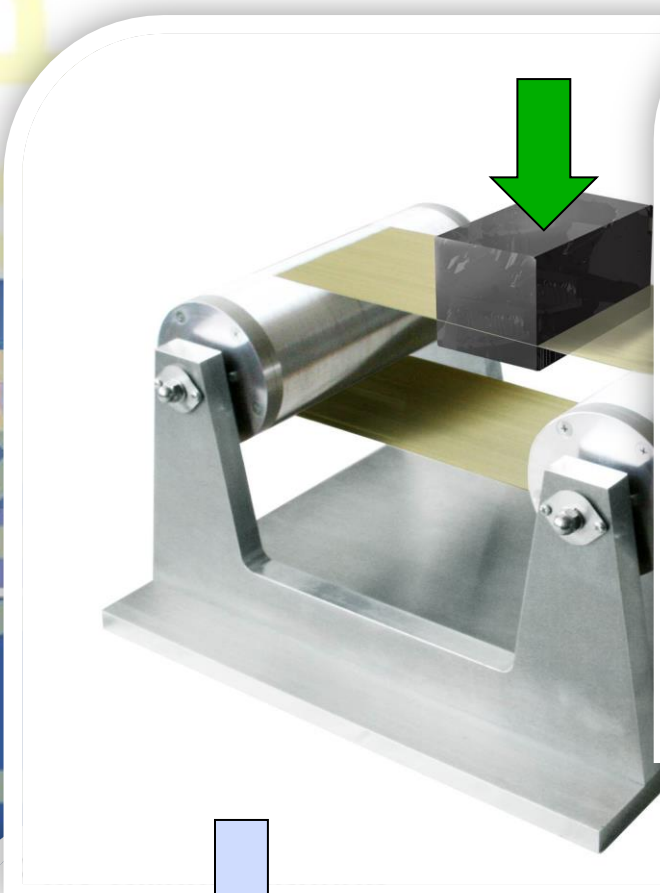
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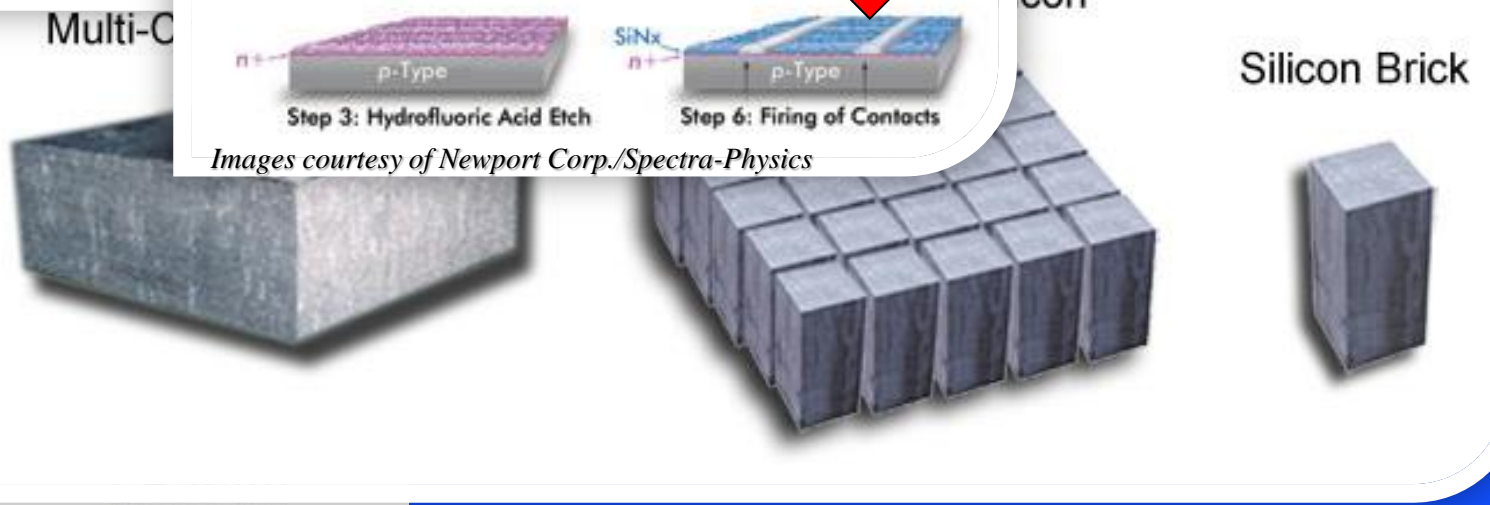


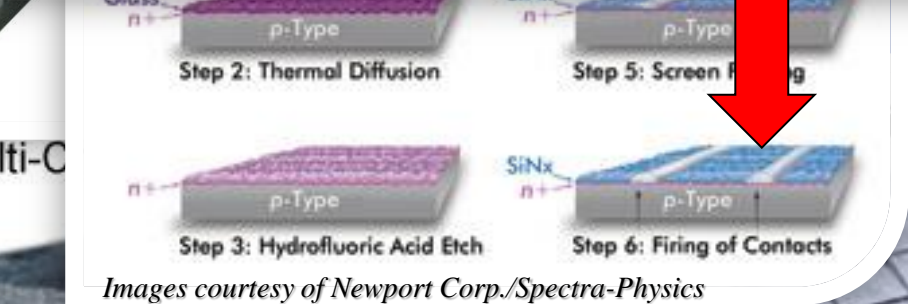
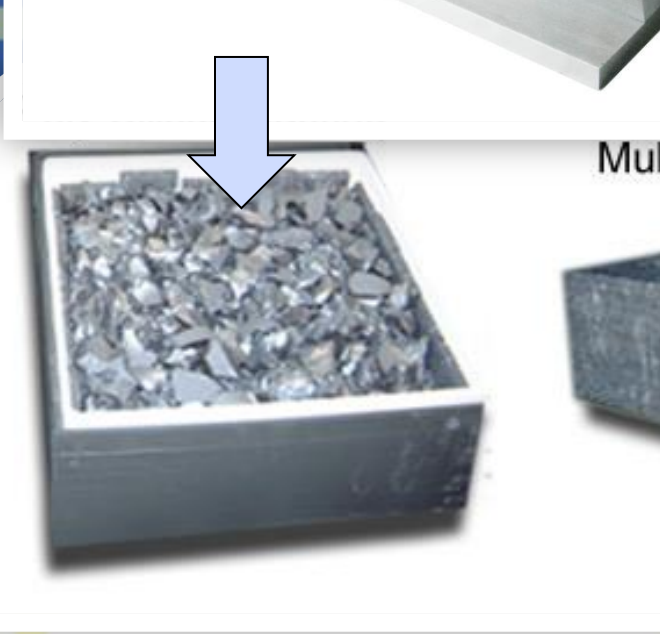
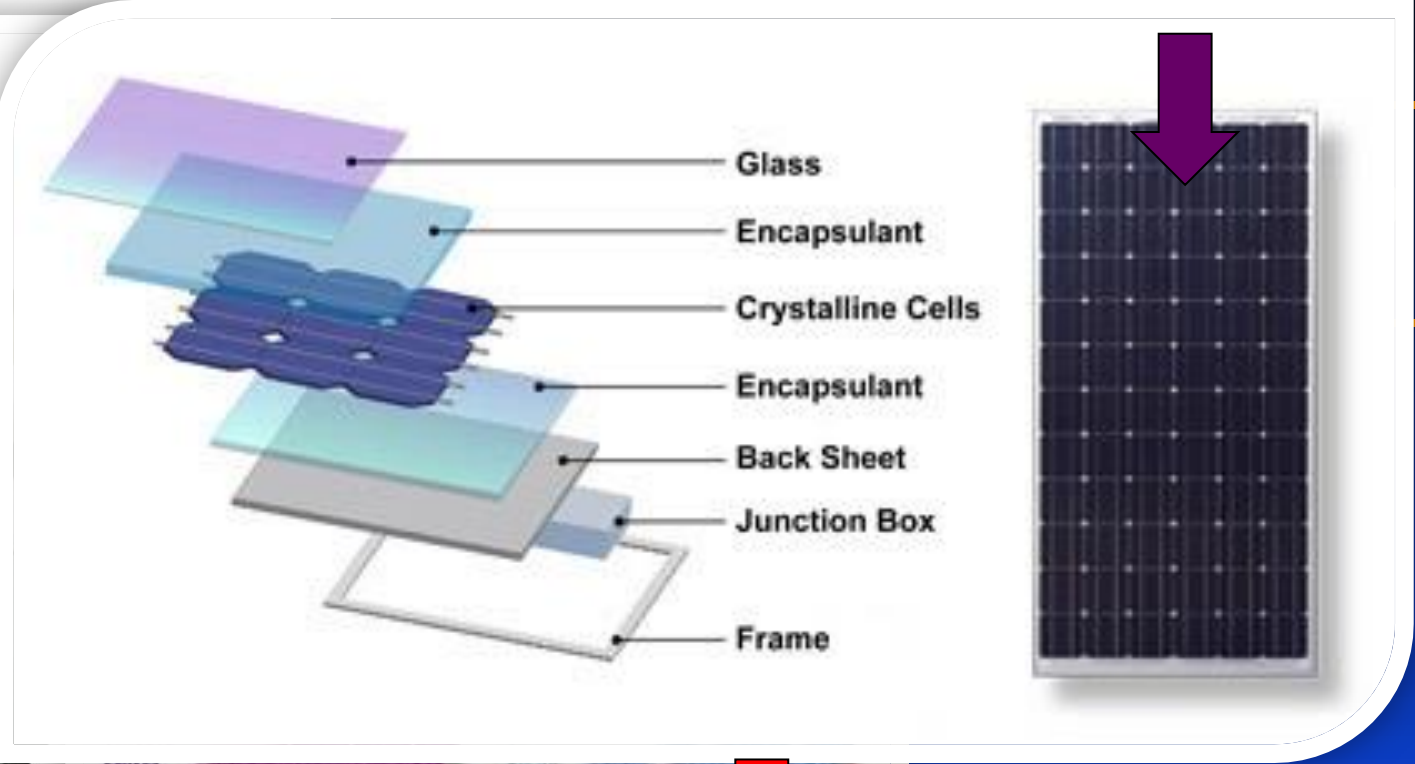
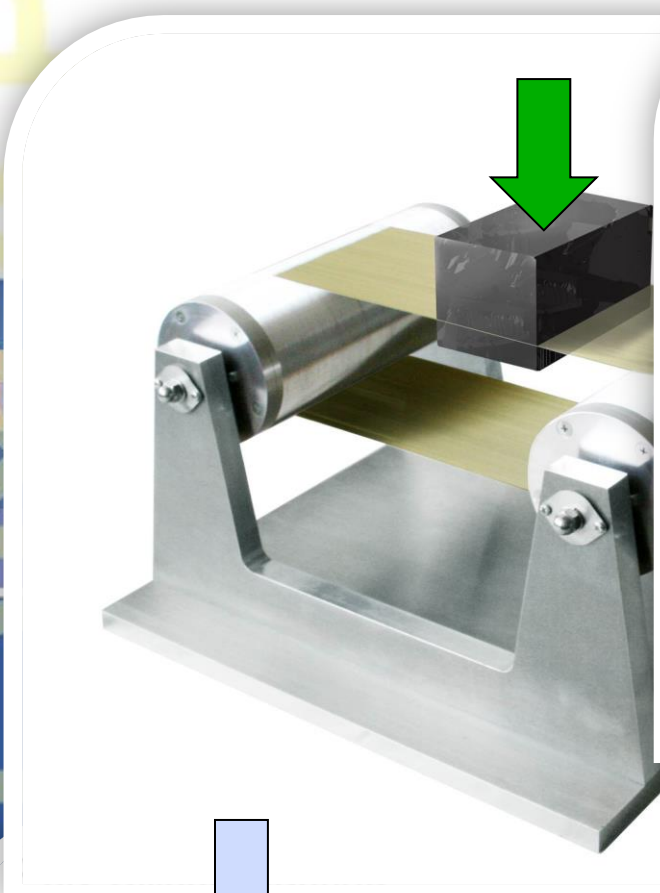
Images courtesy of Newport Corp./Spectra-Physics



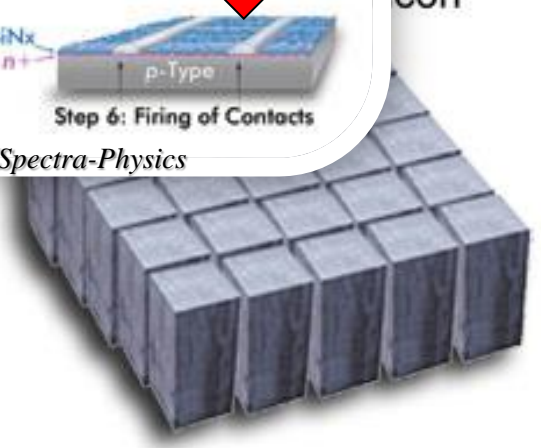
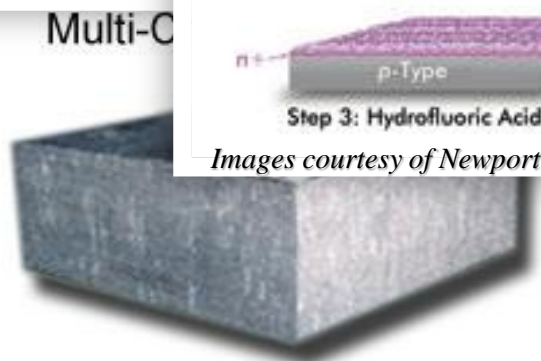


Images courtesy of Newport Corp./Spectra-Physics





Images courtesy of Newport Corp./Spectra-Physics



Silicon Brick

Prices

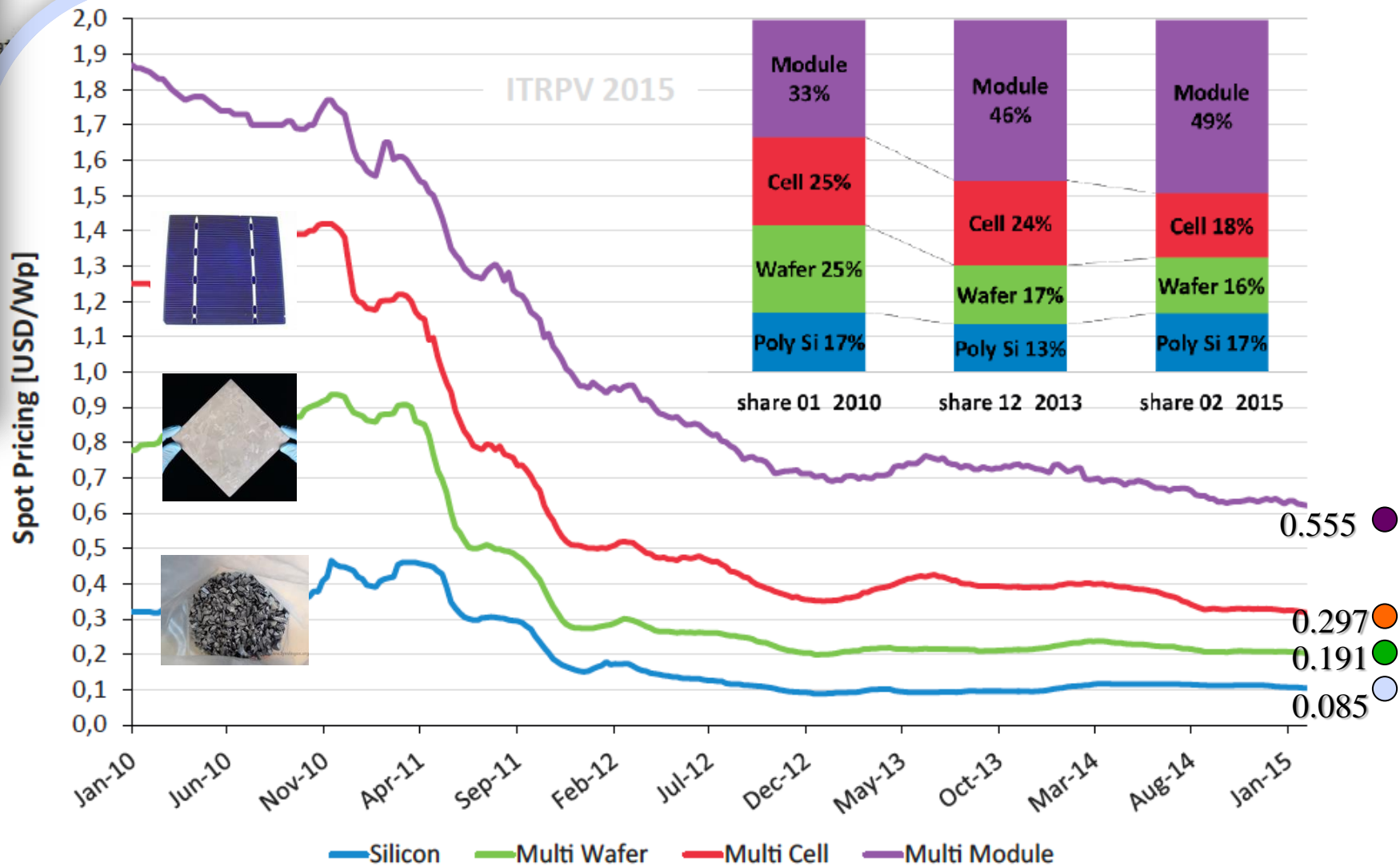


Fig. 2 Price trends for poly-Si, mc-Si wafers, cells, and c-Si modules (assumption: 44.1 Wafers per kg with ~22.7g/wafer, average mc-Si cell efficiency of 17.3% [4,21Wp]); inset: comparison of the proportion of the price attributable to different module cost elements between 01/2010, 01/2013, and 02/2015 (1.86, 0.72, and 0.62 US\$/Wp) [7].

Polysilicon

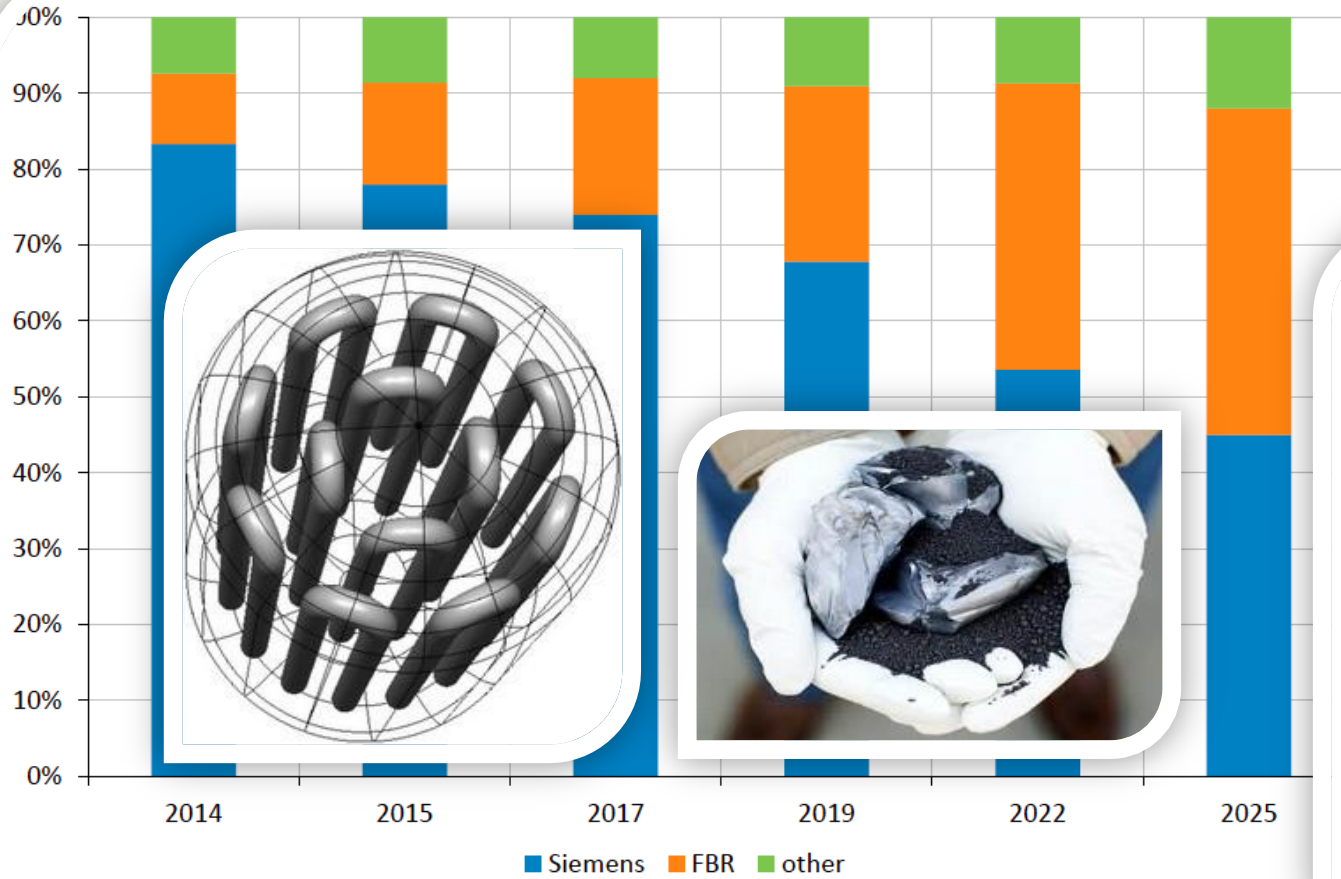
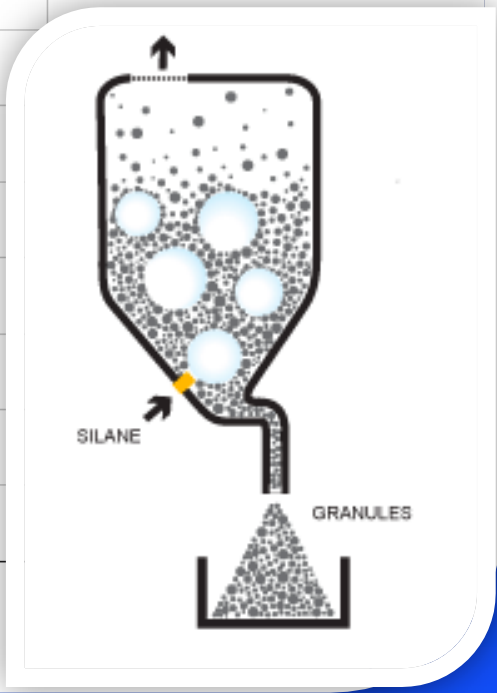
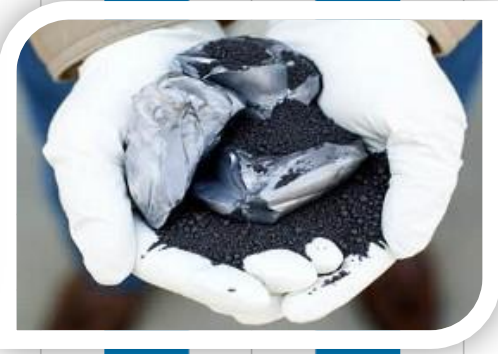


Fig. 3
Expected change in the distribution of poly-Si production technologies.





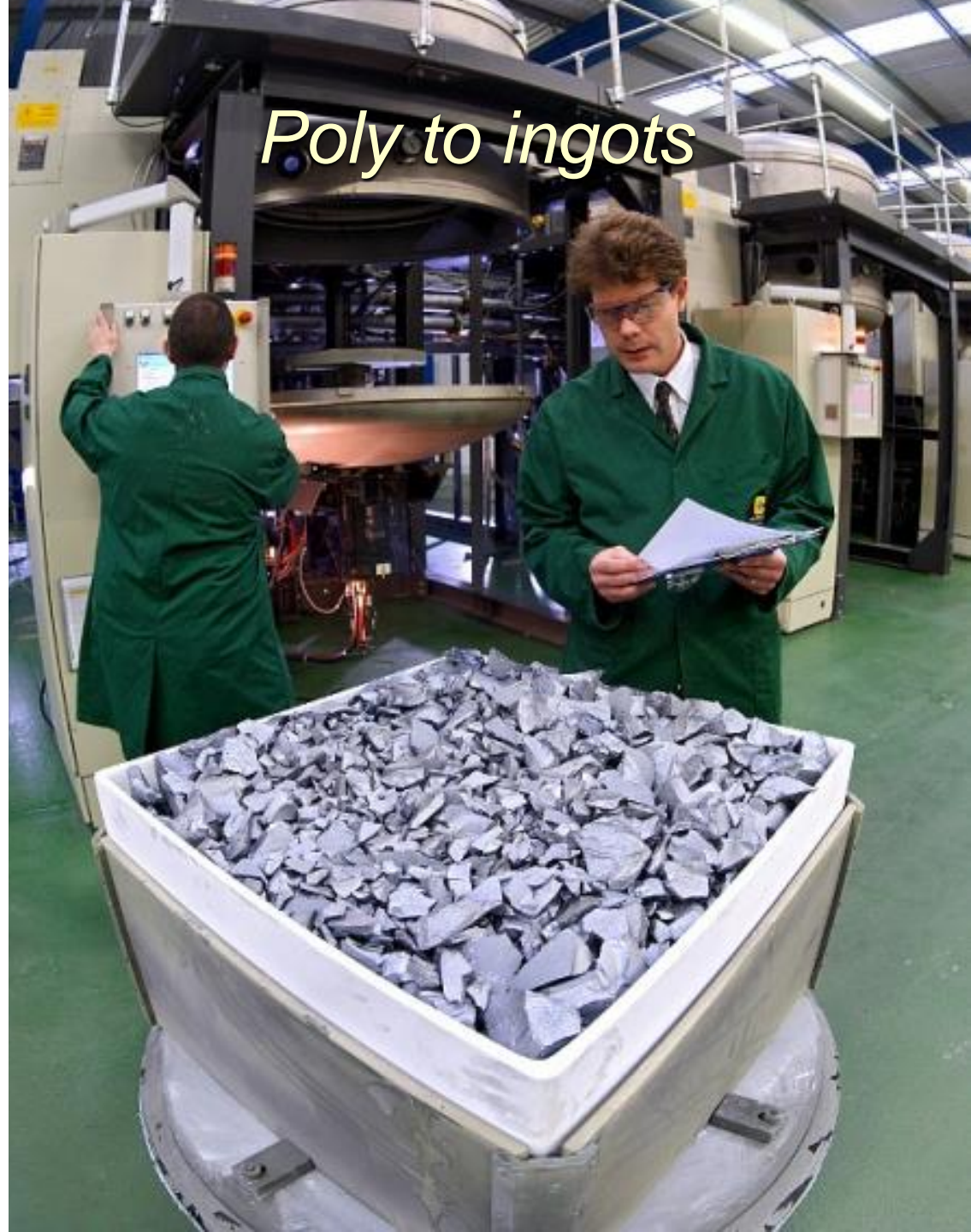
International Technology Roadmap for Photovoltaic



International Technology Roadmap for Photovoltaic (ITRPV)

2014 Results

April 2015



Poly to ingots

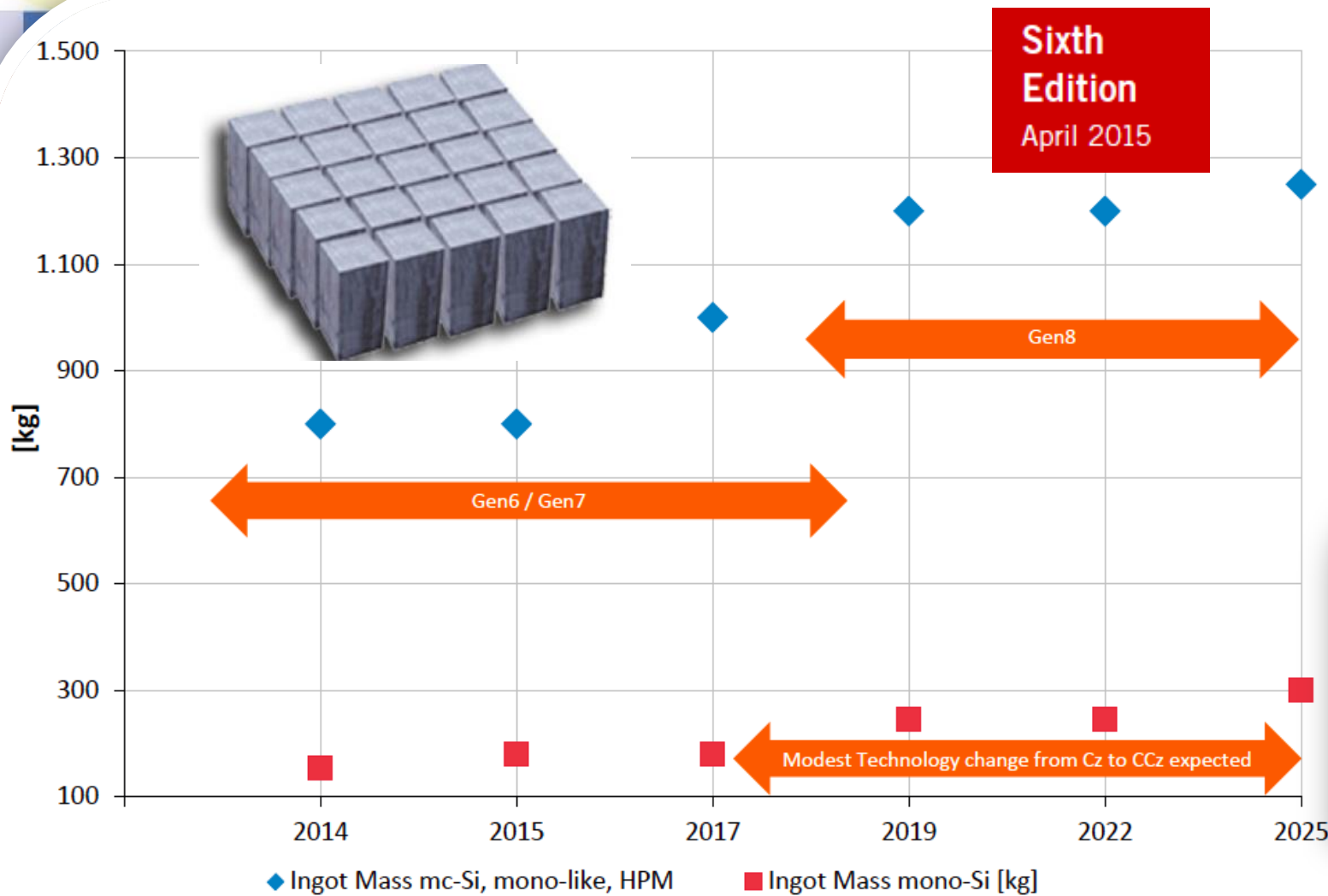
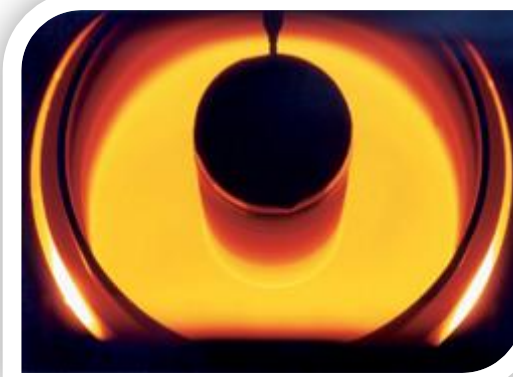


Fig. 12
 Predicted trend for ingot mass for mc-Si, mono-like, and HPmc-Si, as well as for mono-Si.





Poly to ingots

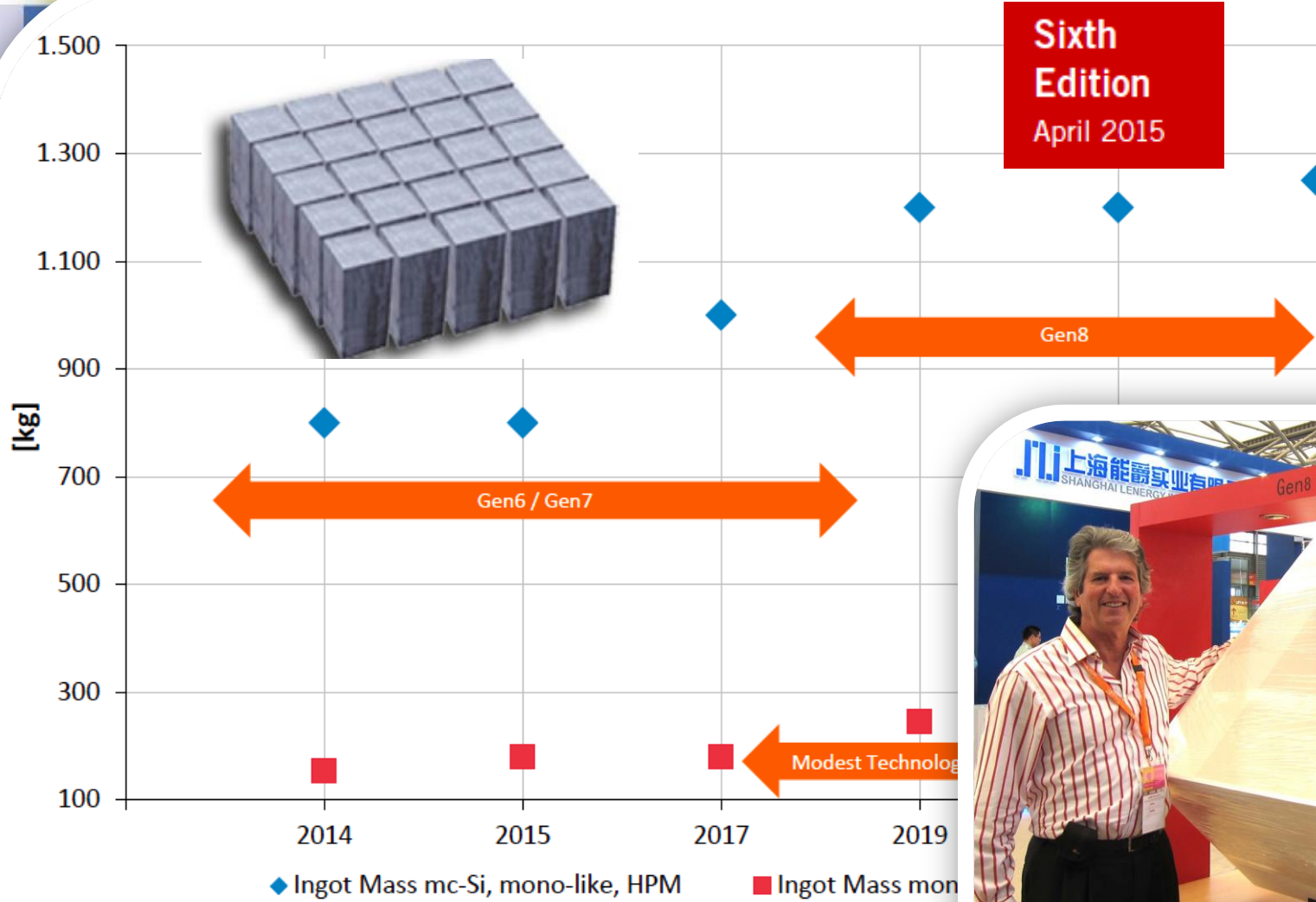


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Poly to ingots

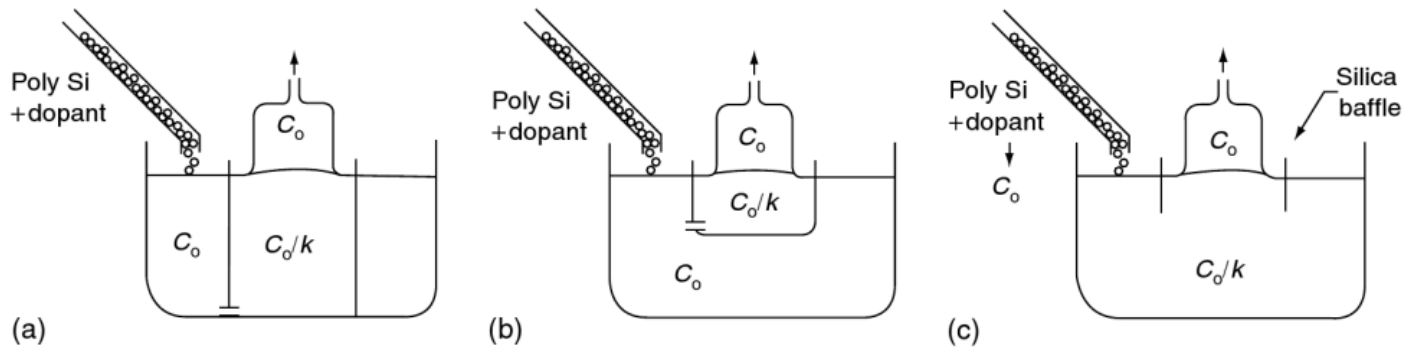
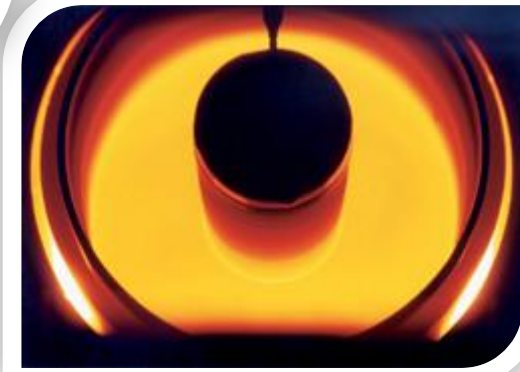
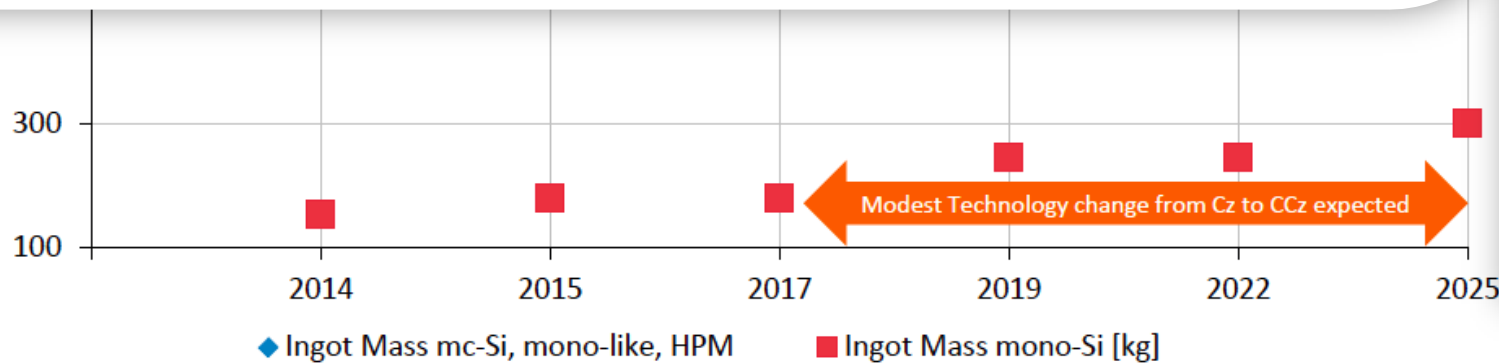


FIGURE 3.45 Crystal growth from double-crucible arrangements with (a) constant melt level or (b) constant inner melt volume, maintained by continuous-feed (c) crystal growth from a single container equipped with a circular silica baffle. Melt level is kept constant by continuous feed. The melt concentration is maintained at C_0/k . (From Lin, W. and Benson, K. E., *Annual Review of Materials Science*, 17, 273, 1987. Reproduced with permission from Annual Reviews.)

Fig. 12

Predicted trend for ingot mass for mc-Si, mono-like, and HPmc-Si, as well as for mono-Si.





Poly to ingots

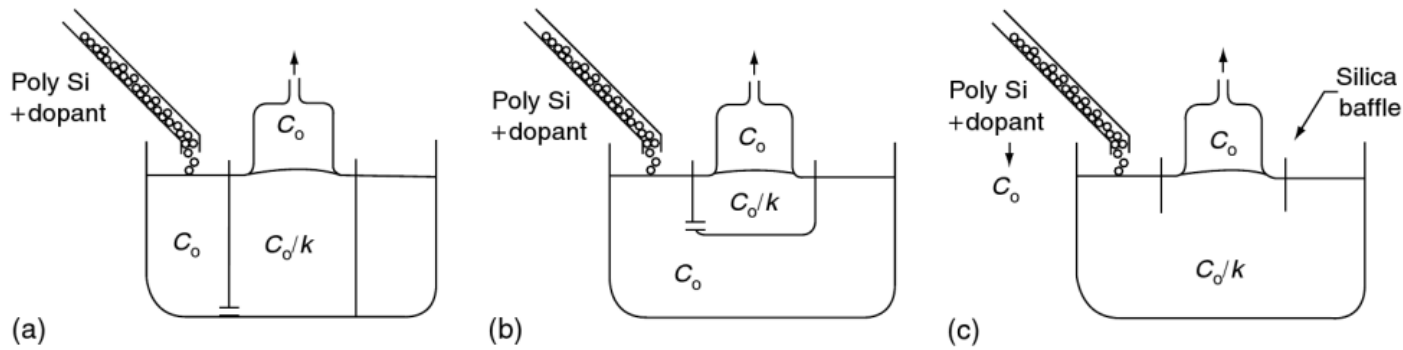


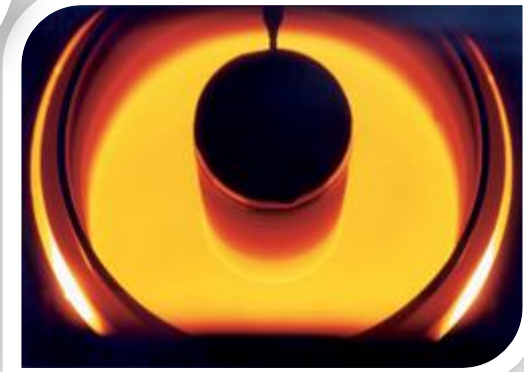
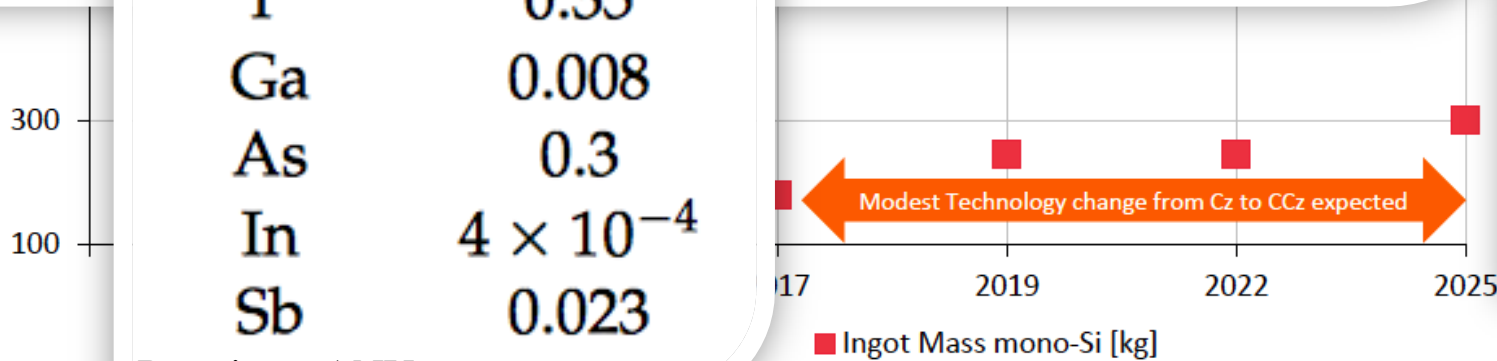
Fig. 12

Predicted trend for ingot mass for mc-Si, mono-like, and HPmc-Si, as well as for mono-Si.

FIGURE 3.45 Crystal growth from double-crucible arrangements with (a) constant melt level or (b) constant inner melt volume, and (c) from a single container equipped with a circular silica baffle. Melt concentration is maintained at C_0/k . (From Lin, W. and Benson, J., 1987. Reproduced with permission from Annual Reviews.)

Dopants	k_0
B	0.8
P	0.35
Ga	0.008
As	0.3
In	4×10^{-4}
Sb	0.023

From a single container equipped with a circular silica baffle. Melt concentration is maintained at C_0/k . (From Lin, W. and Benson, J., 1987. Reproduced with permission from Annual Reviews.)



Semi ITRPV 2015 Roadmap

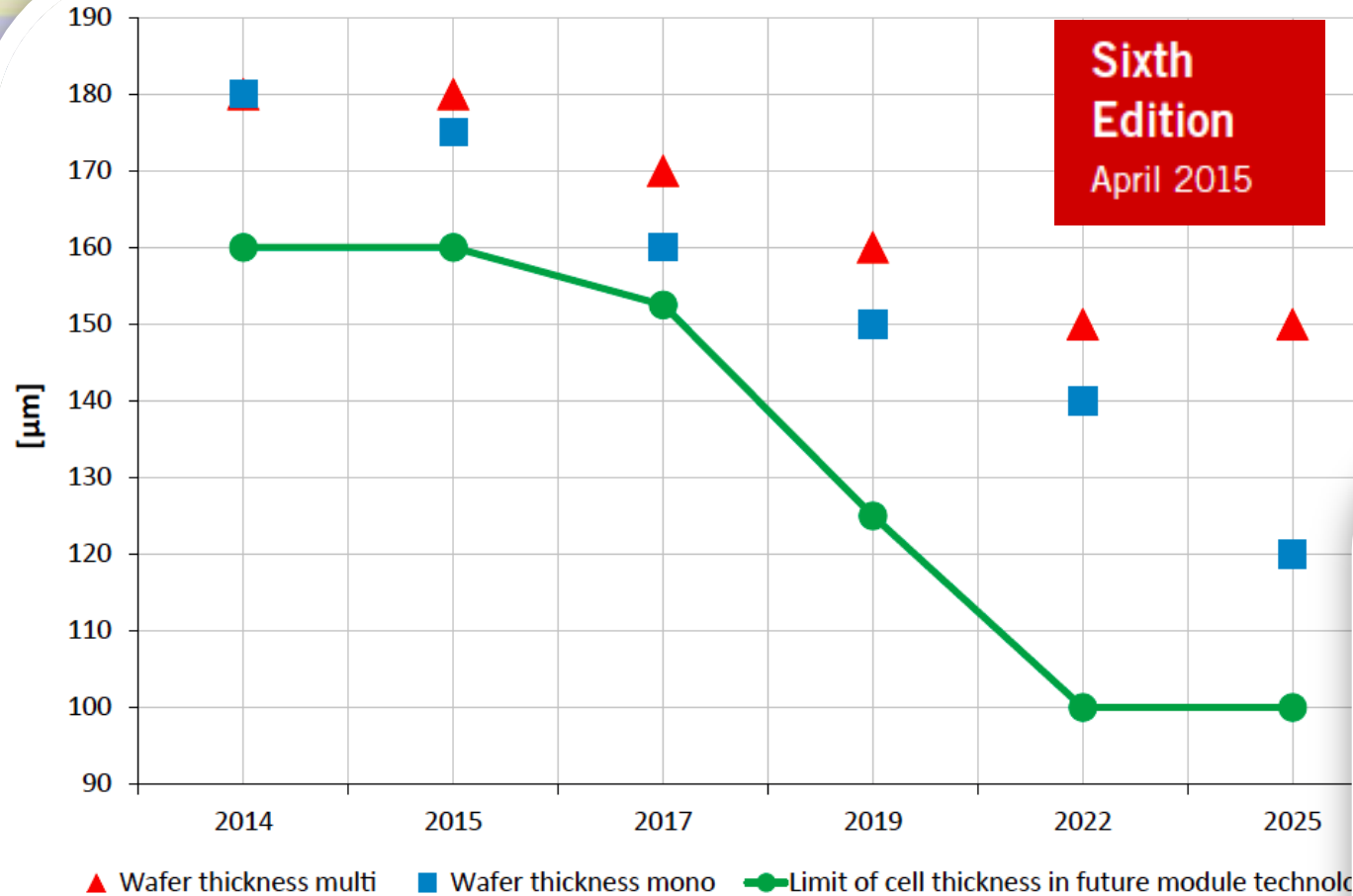
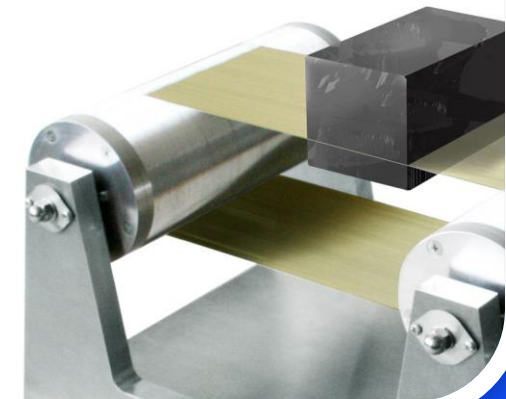


Fig. 5
Predicted trend for minimum as-cut wafer thickness for mass production of c-Si solar cells.



Wafer thickness

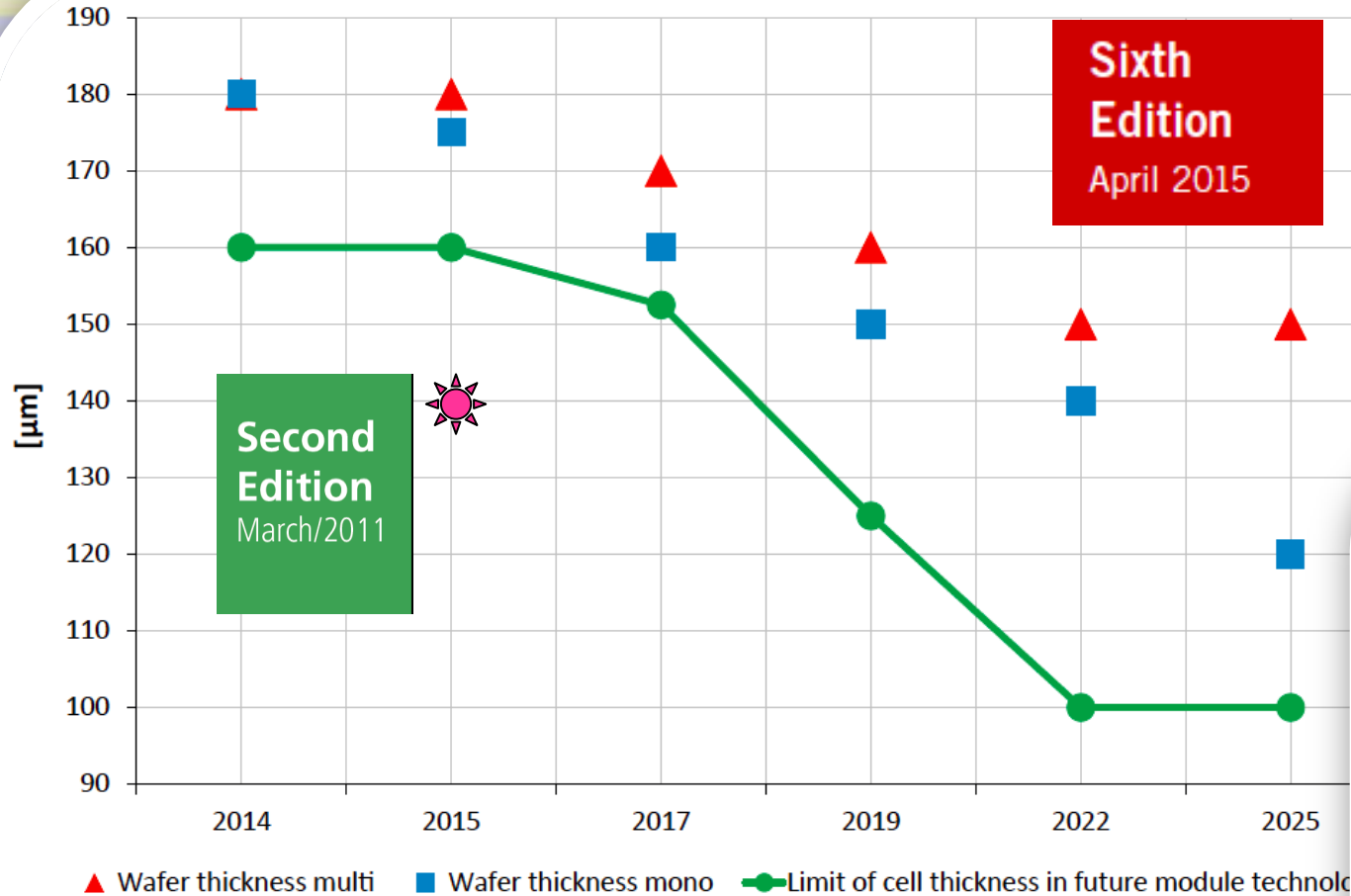
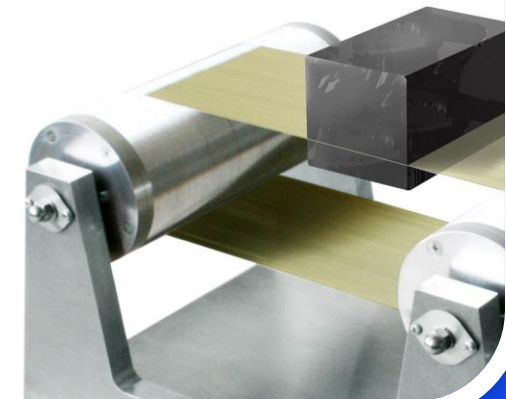
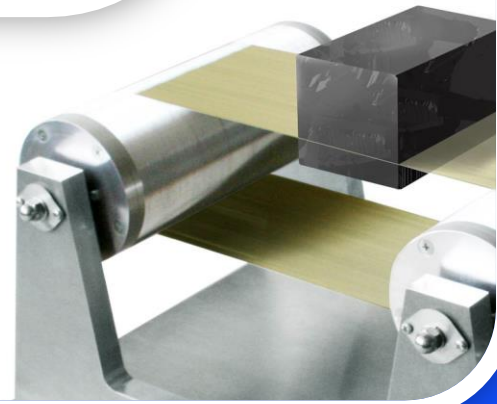
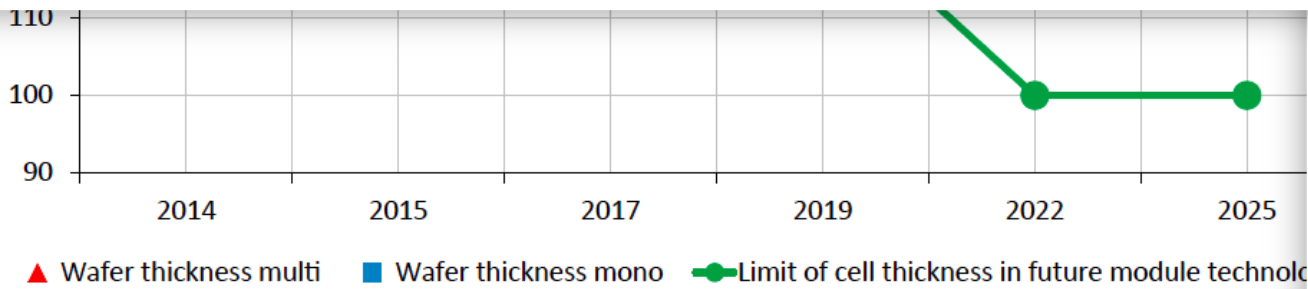
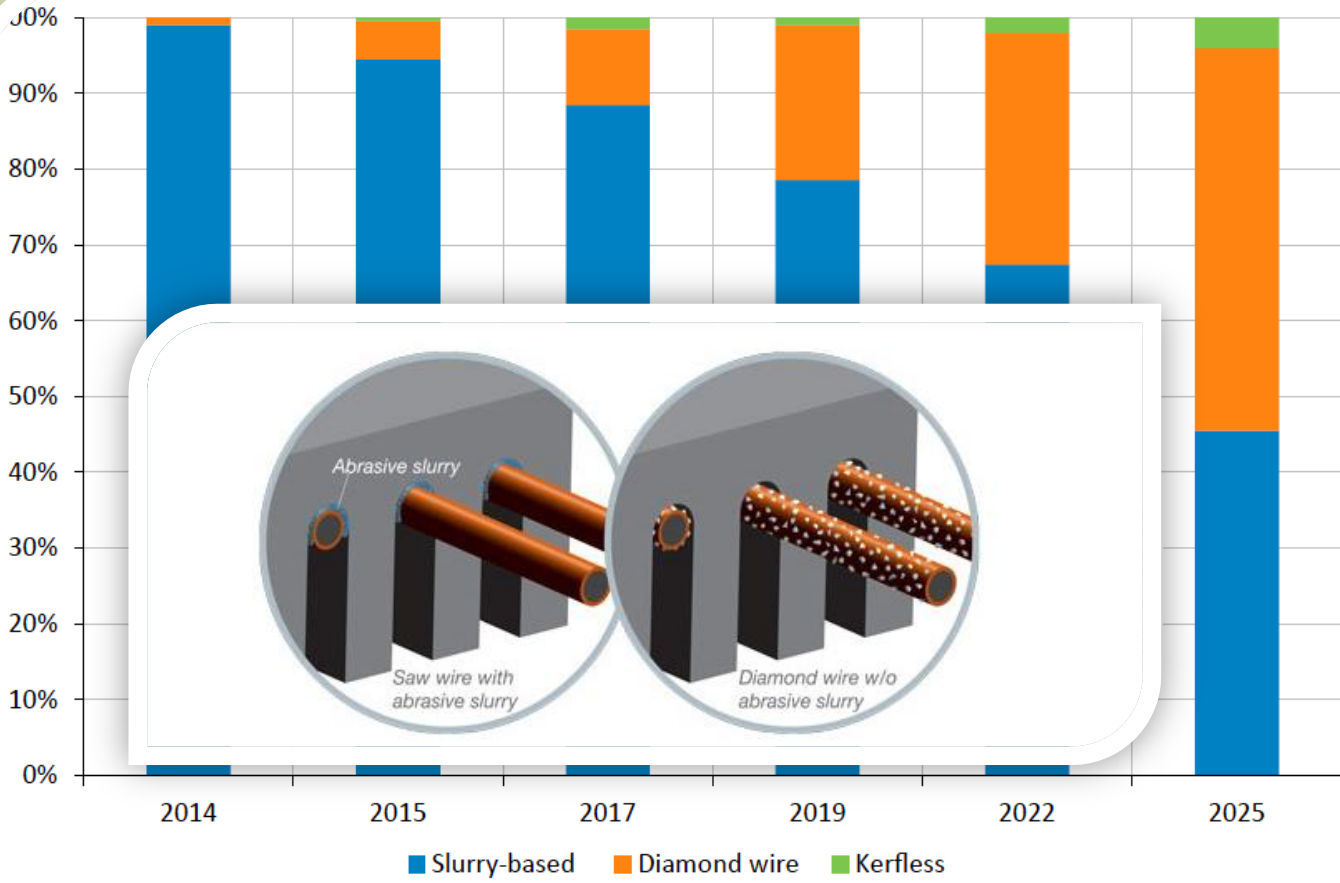


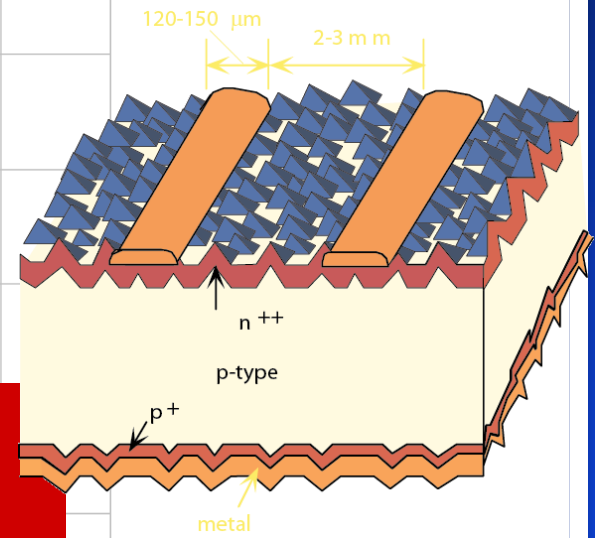
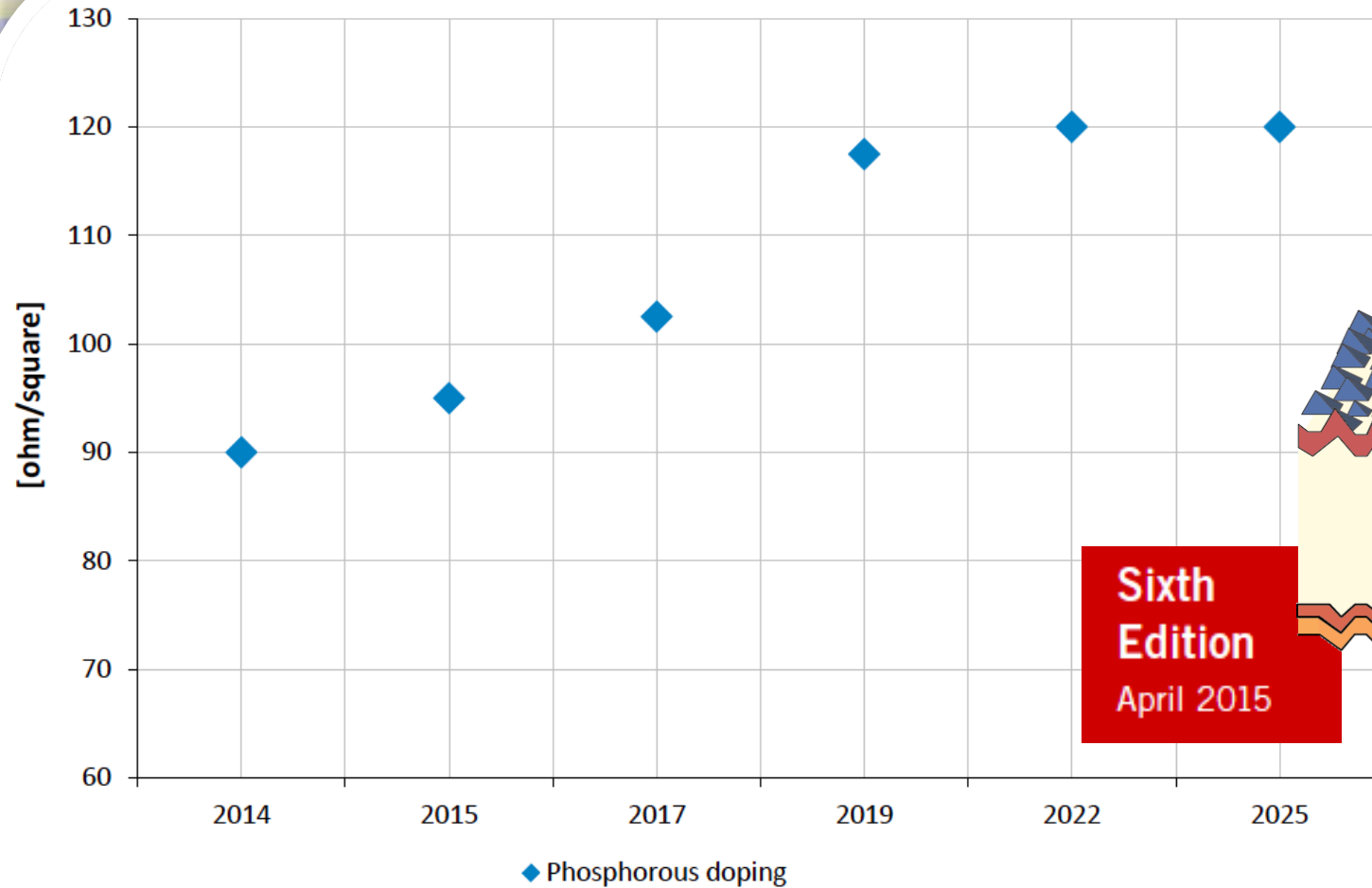
Fig. 5
 Predicted trend for minimum as-cut wafer thickness for mass production of c-Si solar cells.





Emitter diffusion

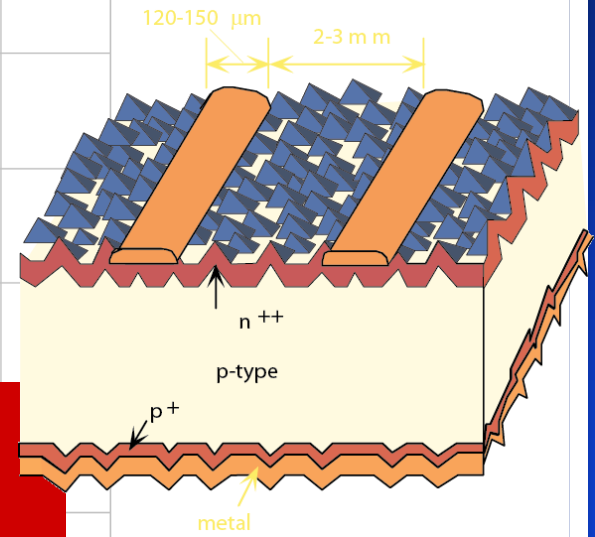
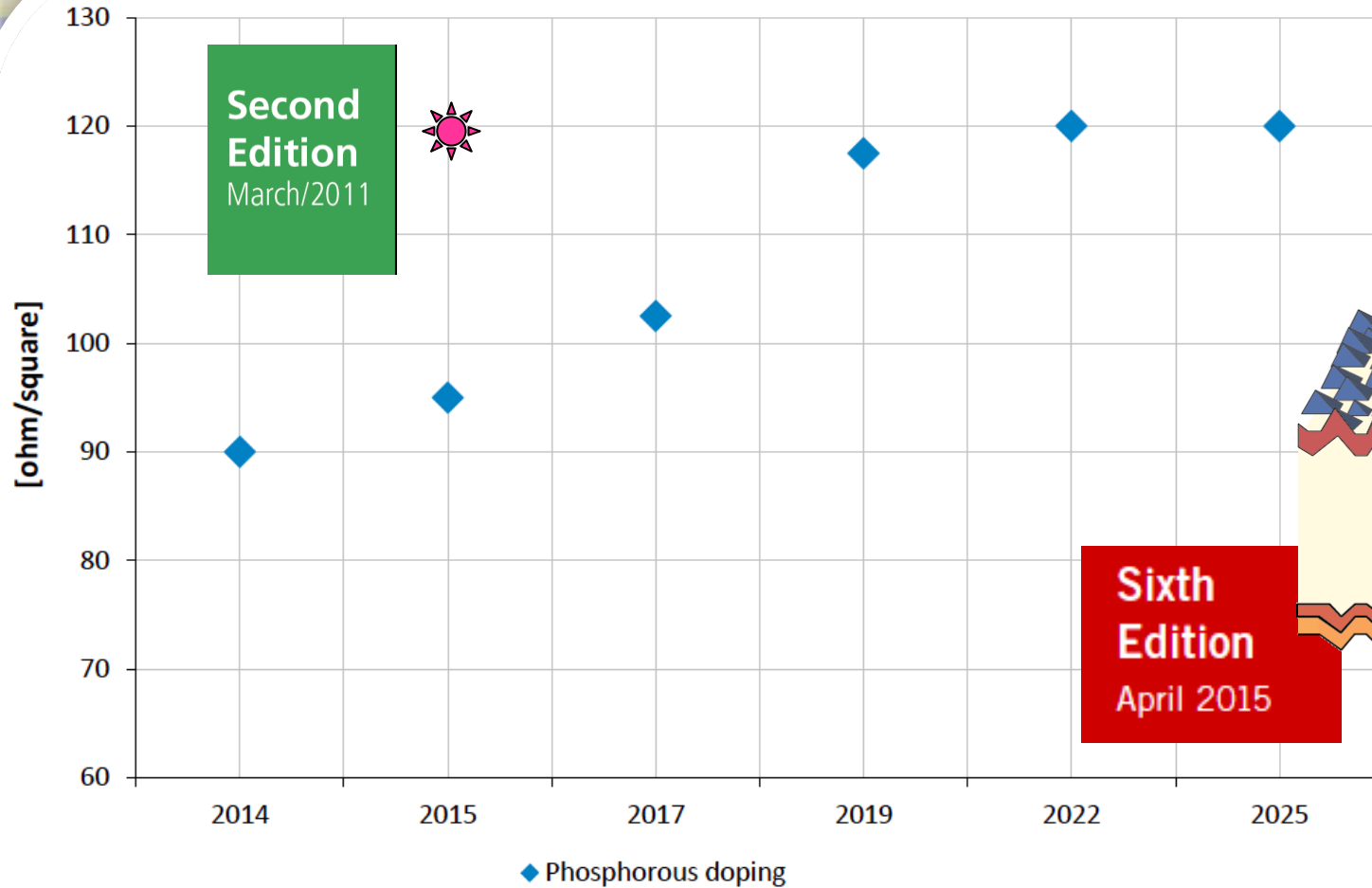
Fig. 17
Expected trend for emitter sheet resistance.



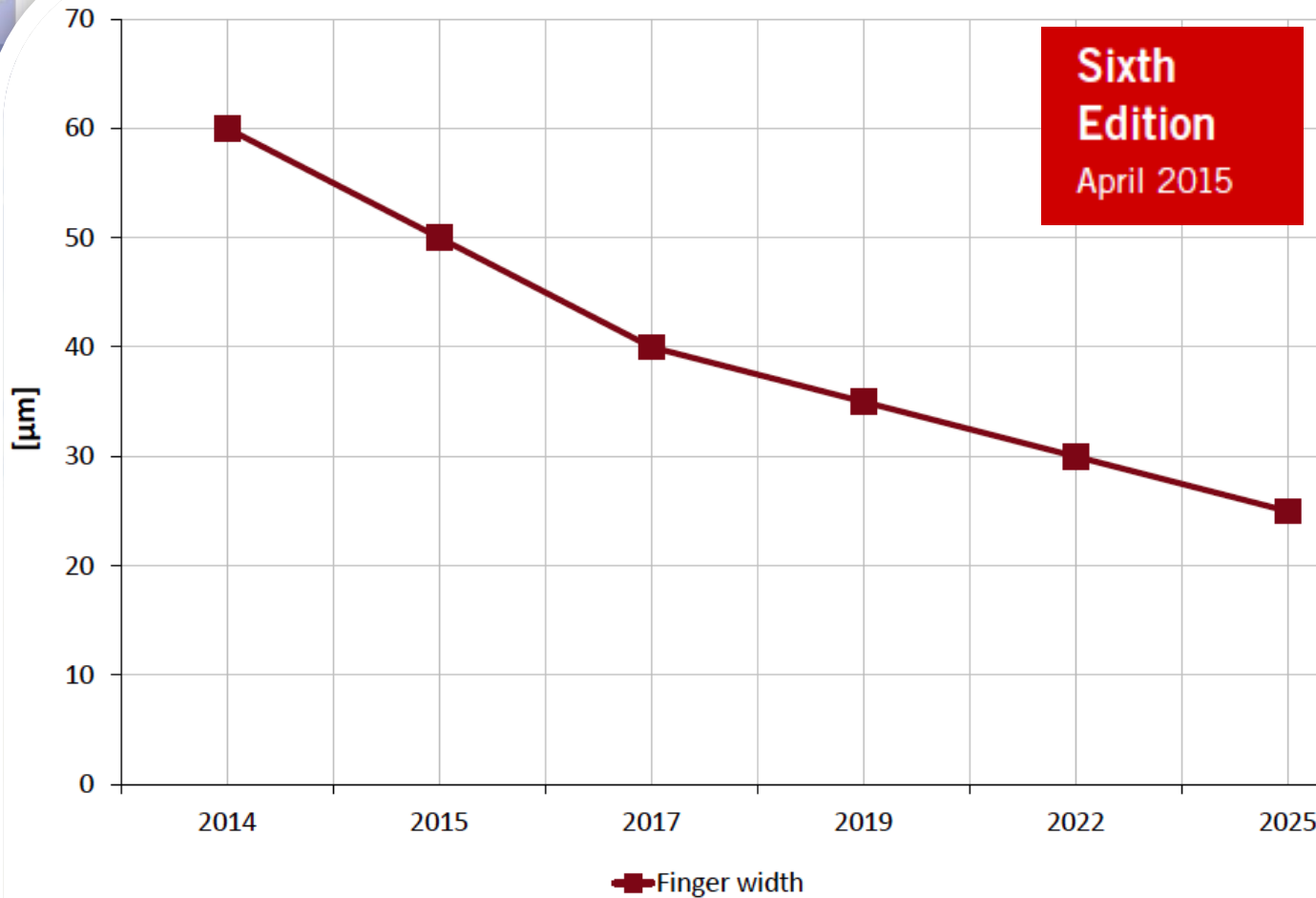
Sixth Edition
April 2015

Emitter diffusion

Fig. 17
Expected trend for emitter sheet resistance.

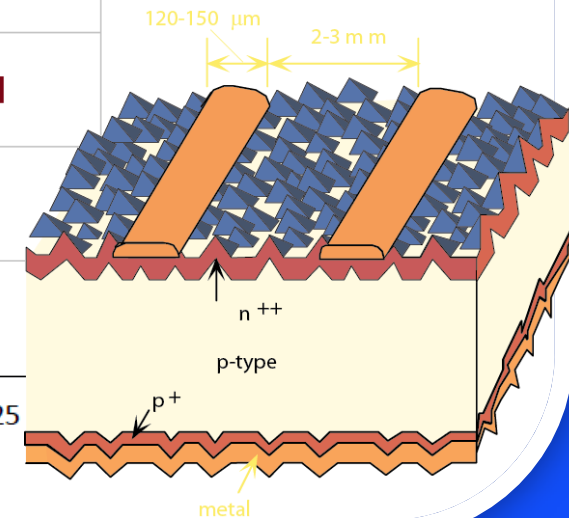


Finger width



Sixth Edition
April 2015

Fig. 20
Predicted trend for finger width in screen printing. Finger width needs to be reduced without any significant reduction in conductivity.



Finger width

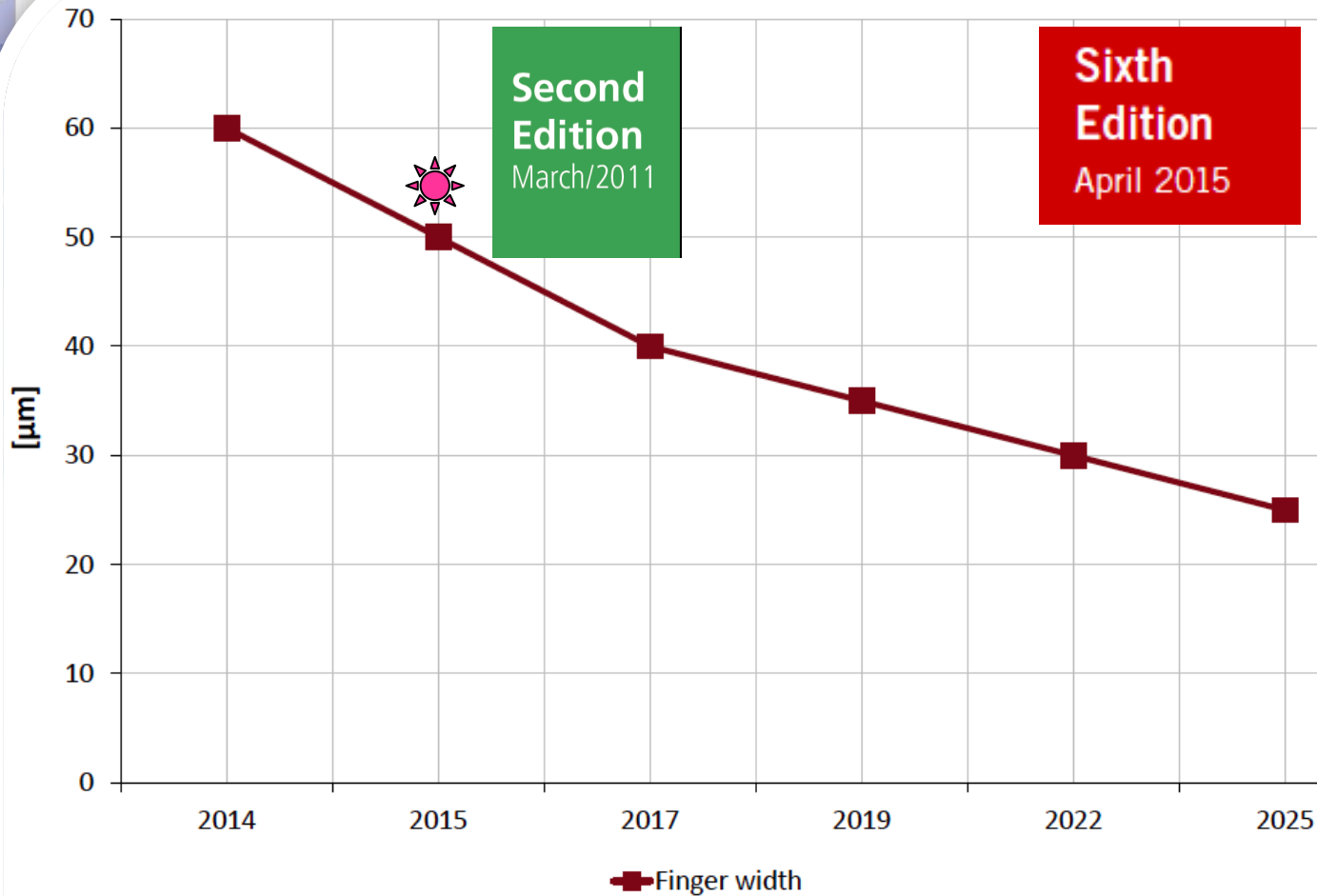
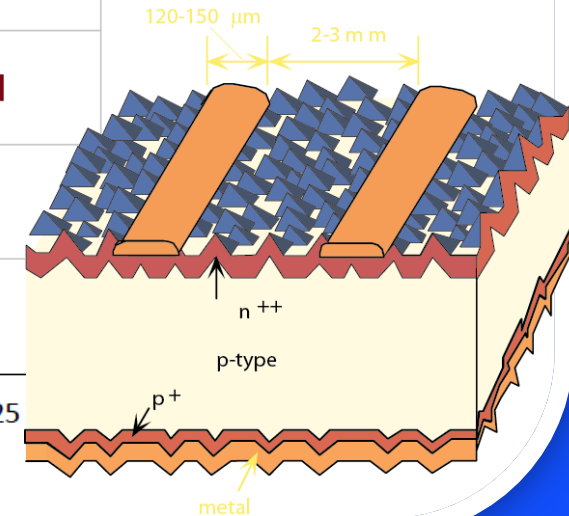
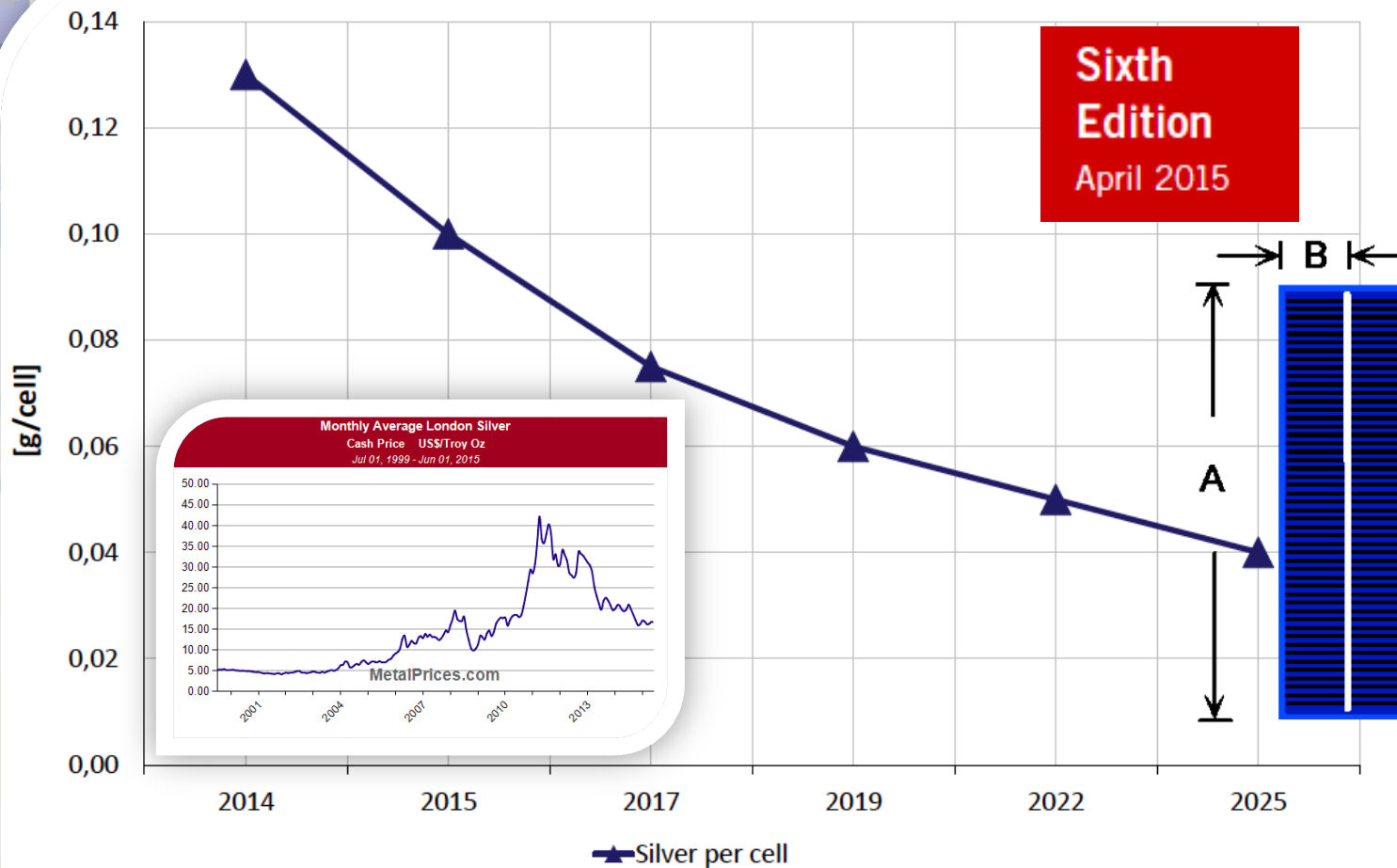


Fig. 20
Predicted trend for finger width in screen printing. Finger width needs to be reduced without any significant reduction in conductivity.



Silver

Sixth



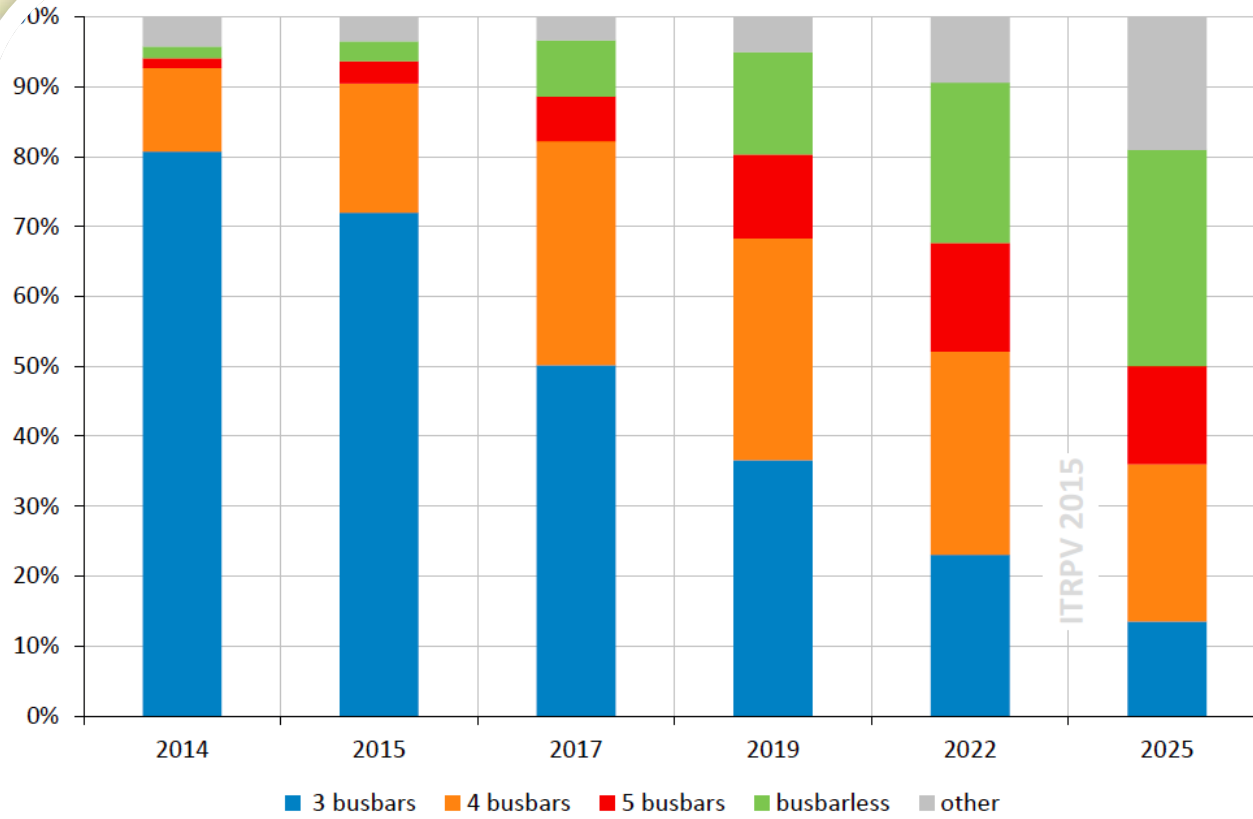
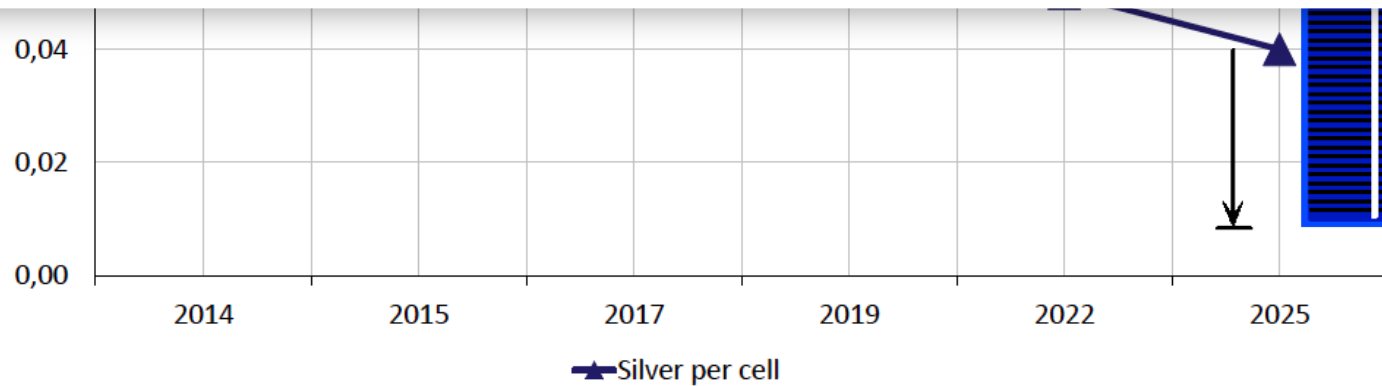


Fig. 22
Worldwide market share
for different busbar
technologies.

remaining silver
(156x156mm²).



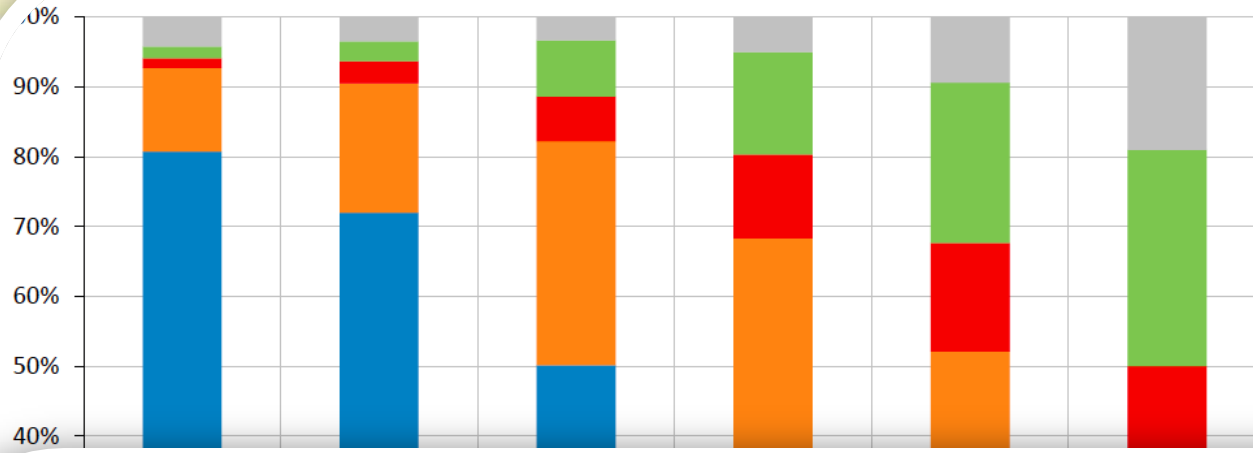


Fig. 22
Worldwide market share for different busbar technologies.

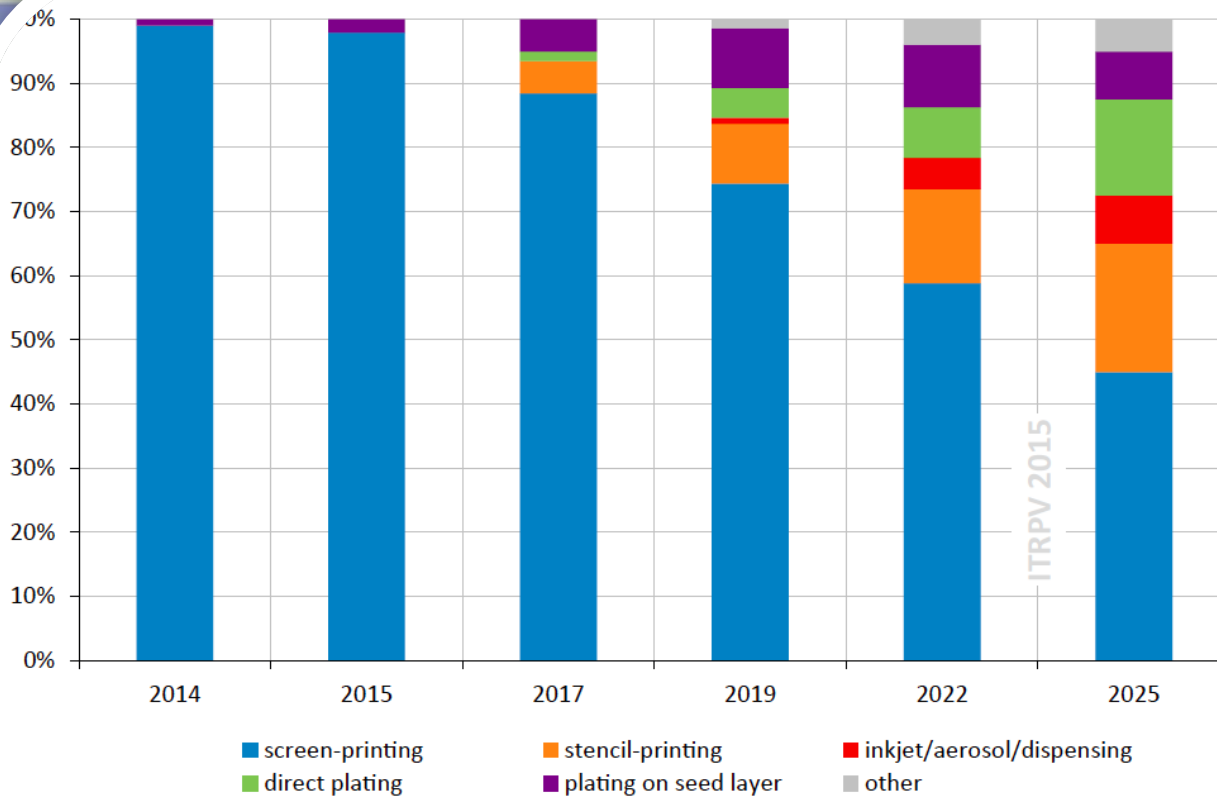
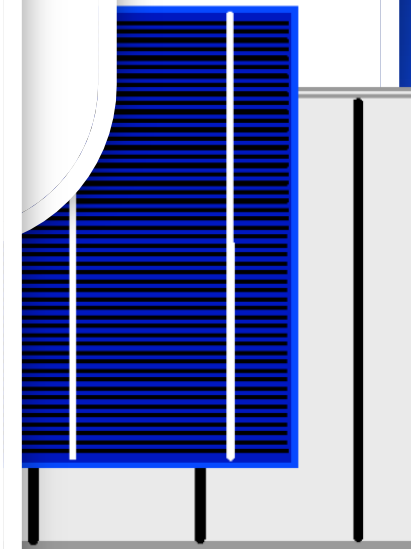


Fig. 21
Predicted trend for different metallization technologies.

remaining silver
(156x156mm²).



Pb?

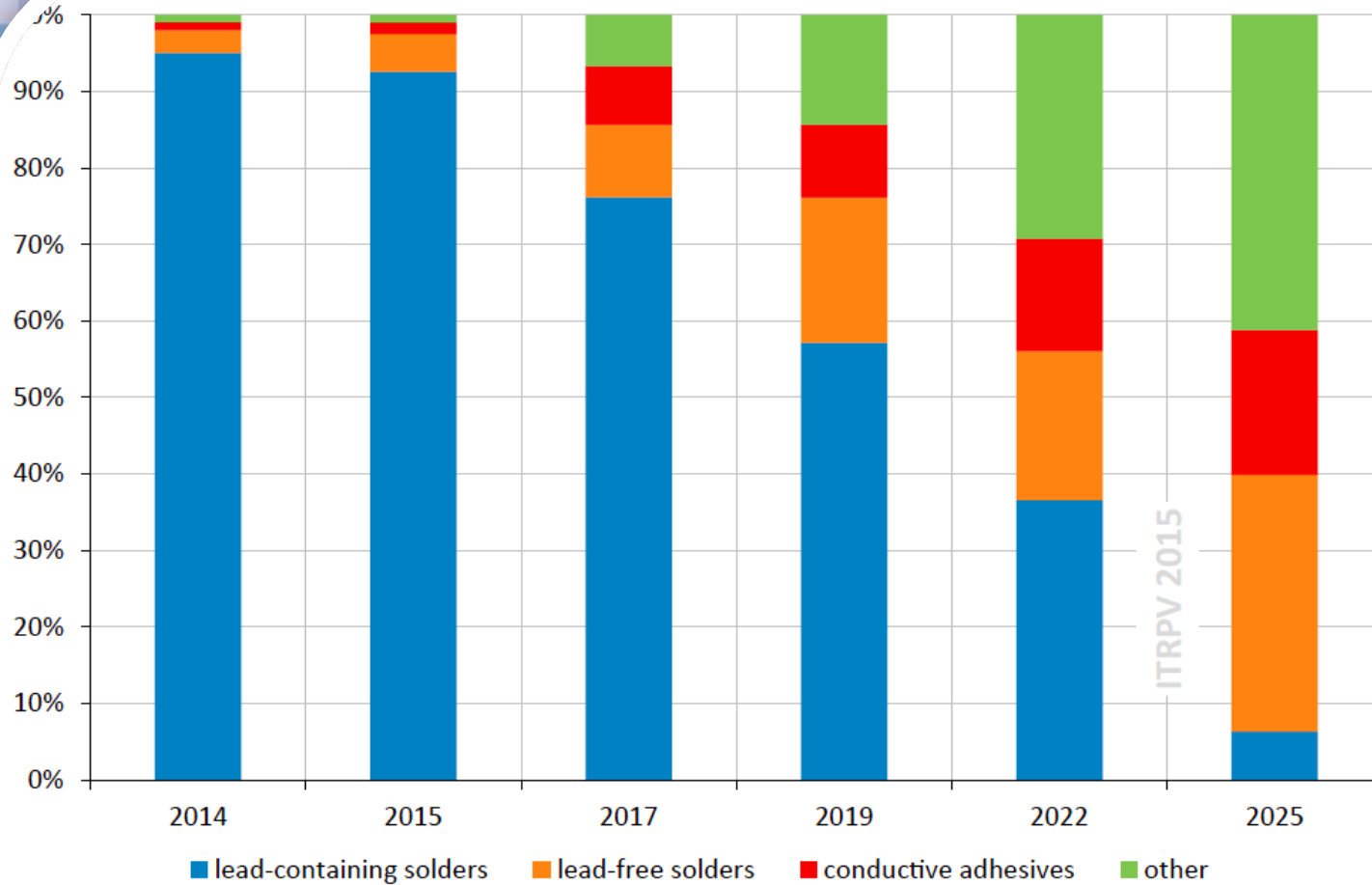


Fig. 9
Expected market shares for different cell connection technologies.

82
Pb
207.2

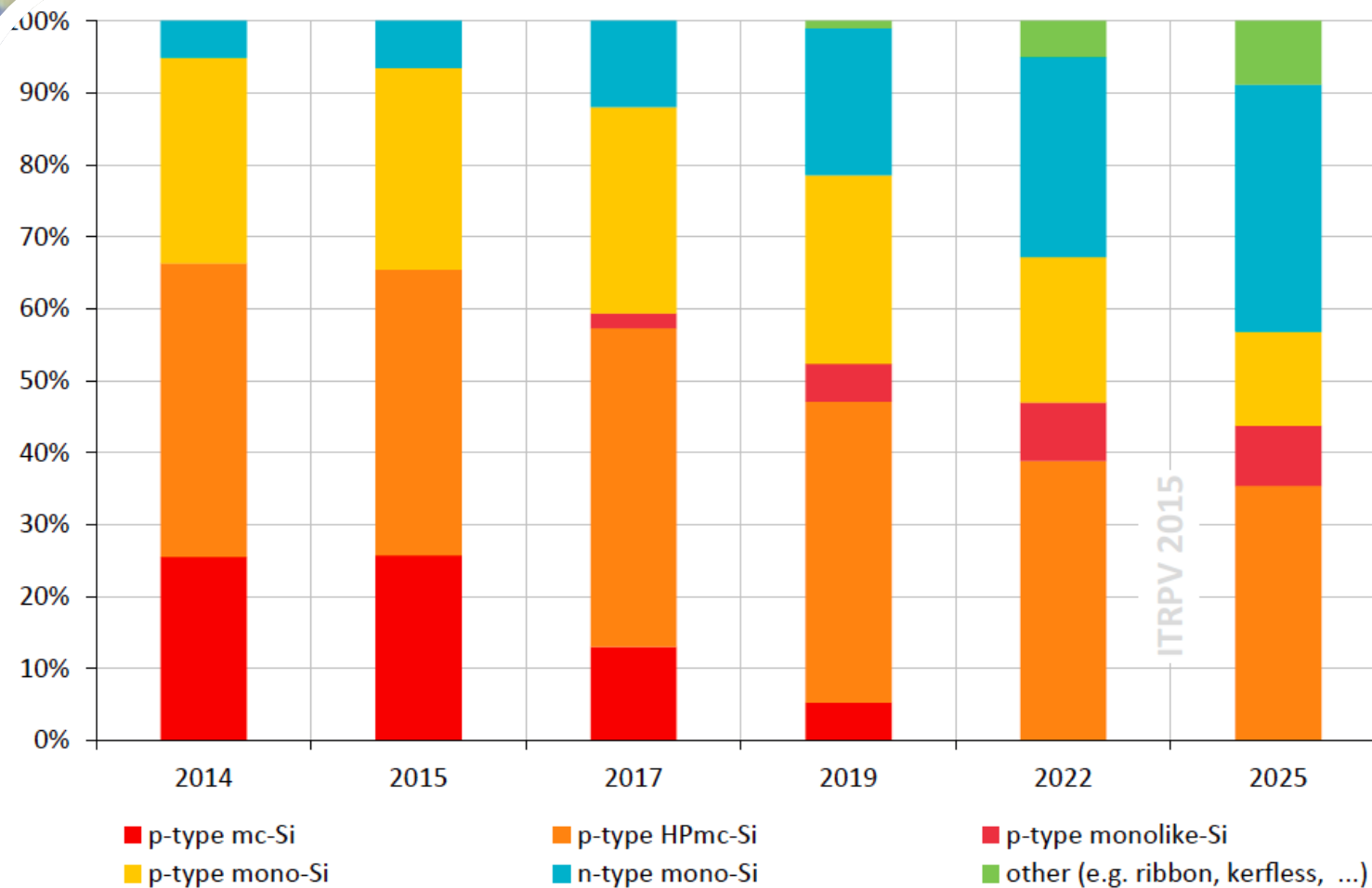


Fig. 24
World market shares for different wafer types.



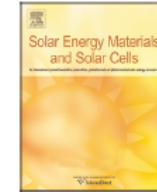


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Higher quality mono-like cast silicon with induced grain boundaries

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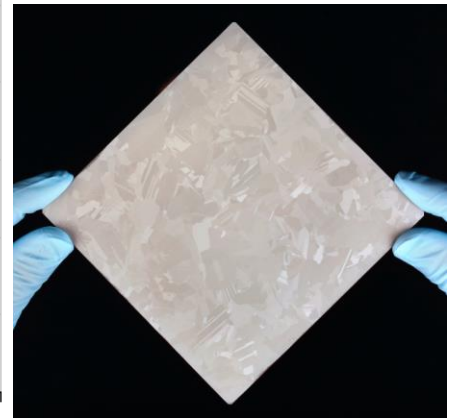
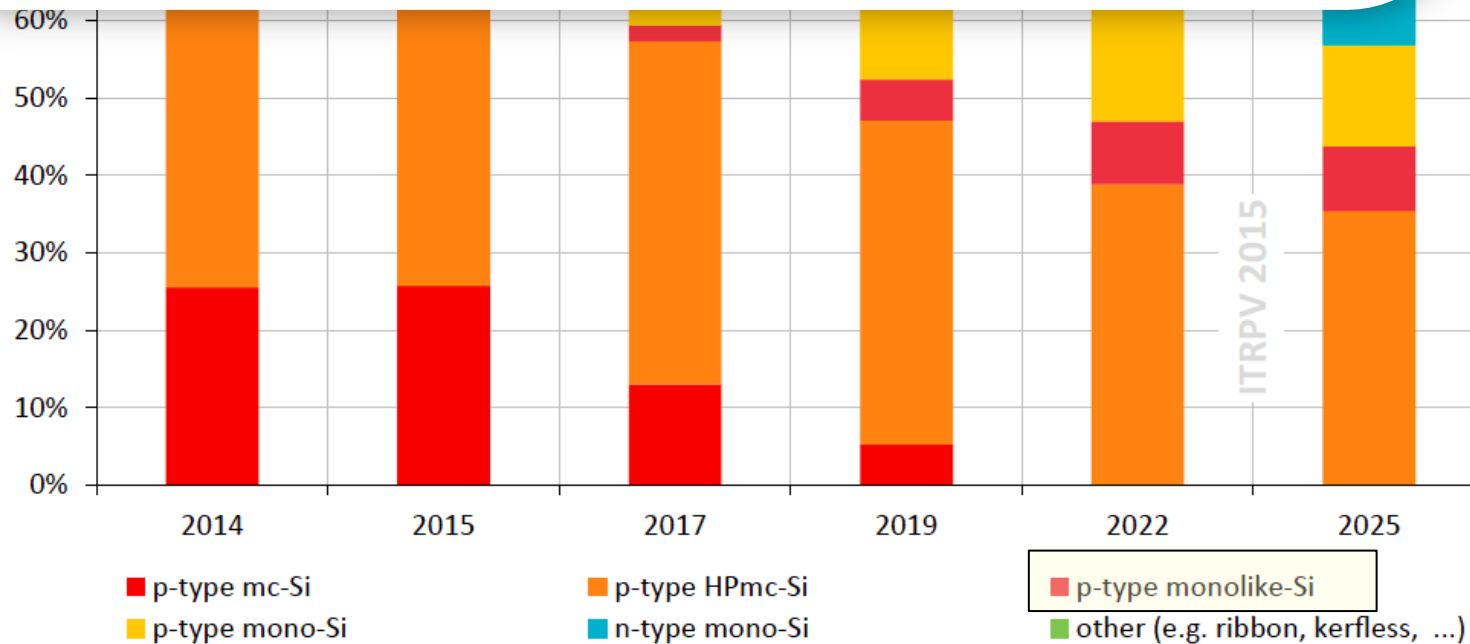


Fig. 24
World market shares for different wafer types.

er/polarity

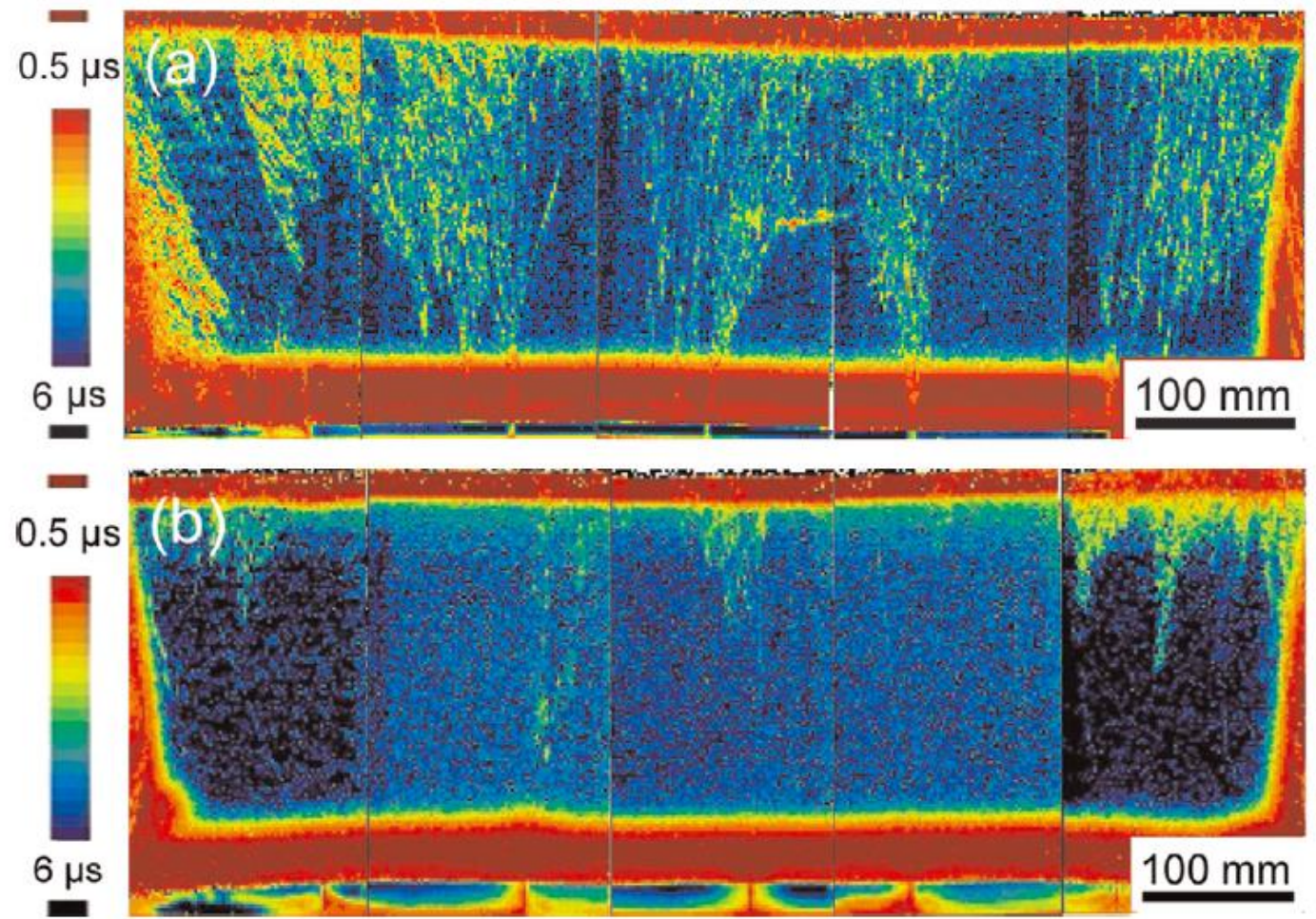


Fig. 5. Carrier lifetime mapping of the cross-section of (a) ingot A and (b) ingot B.

- p-type mc-Si
- p-type HPmc-Si
- p-type monolike-Si
- p-type mono-Si
- n-type mono-Si
- other (e.g. ribbon, kerfless, ...)



Fig. 24 World market shares for different wafer types.



Cell technology

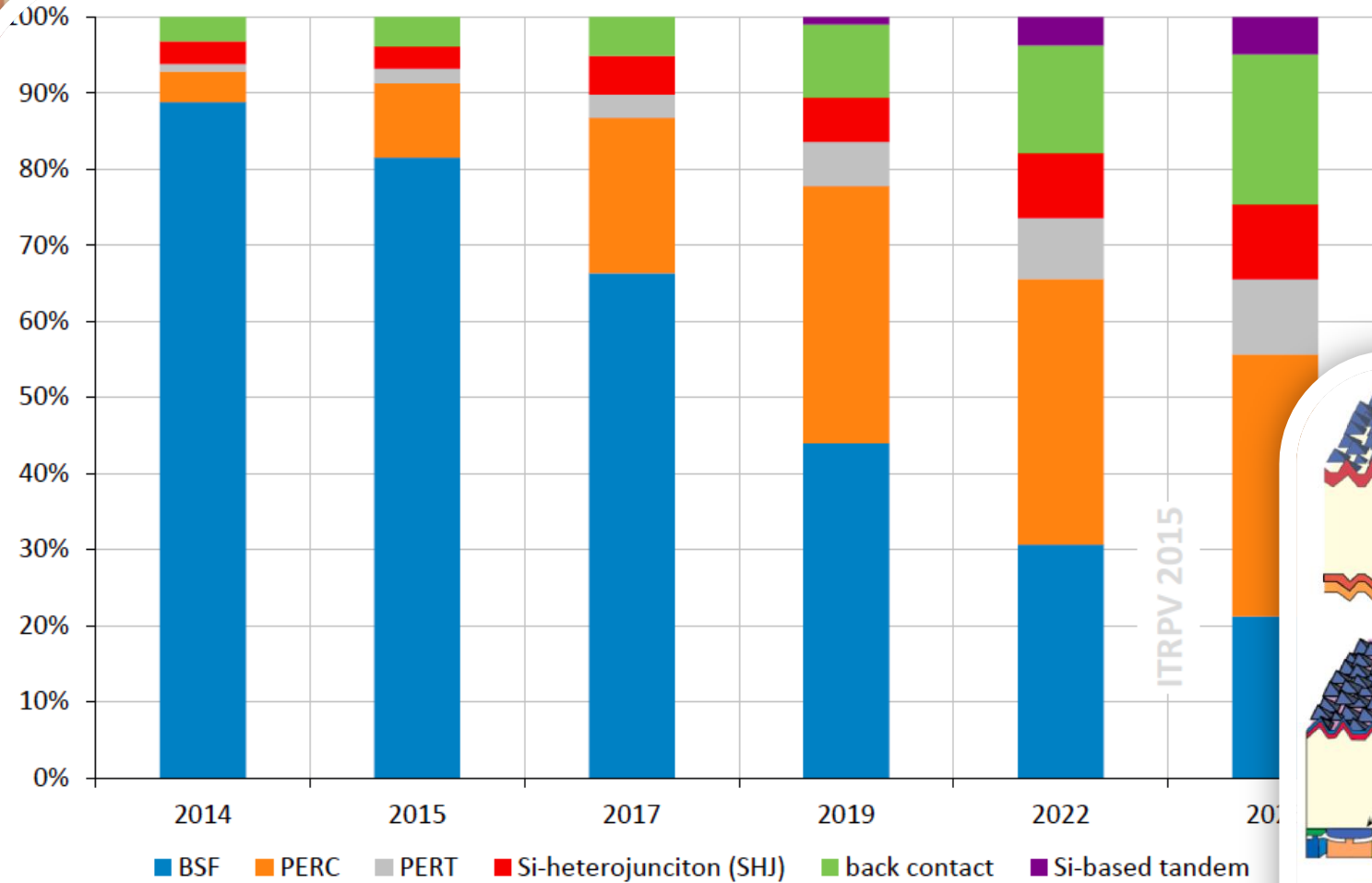
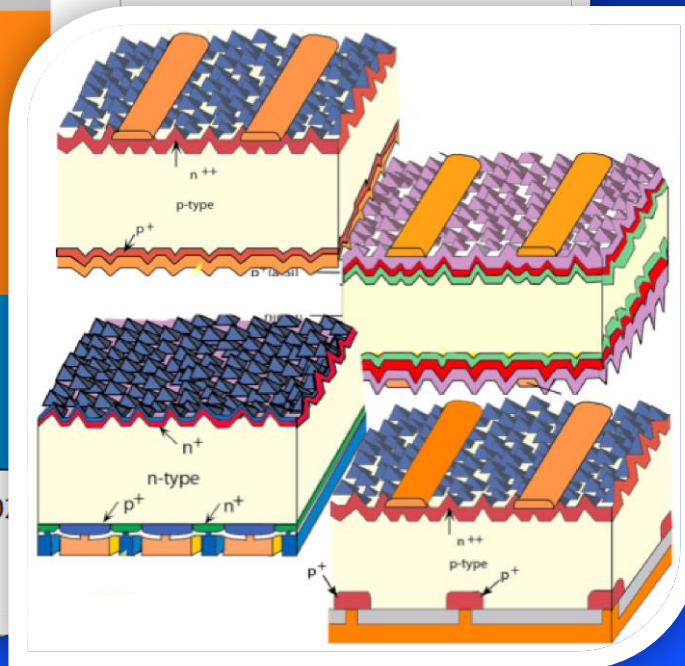
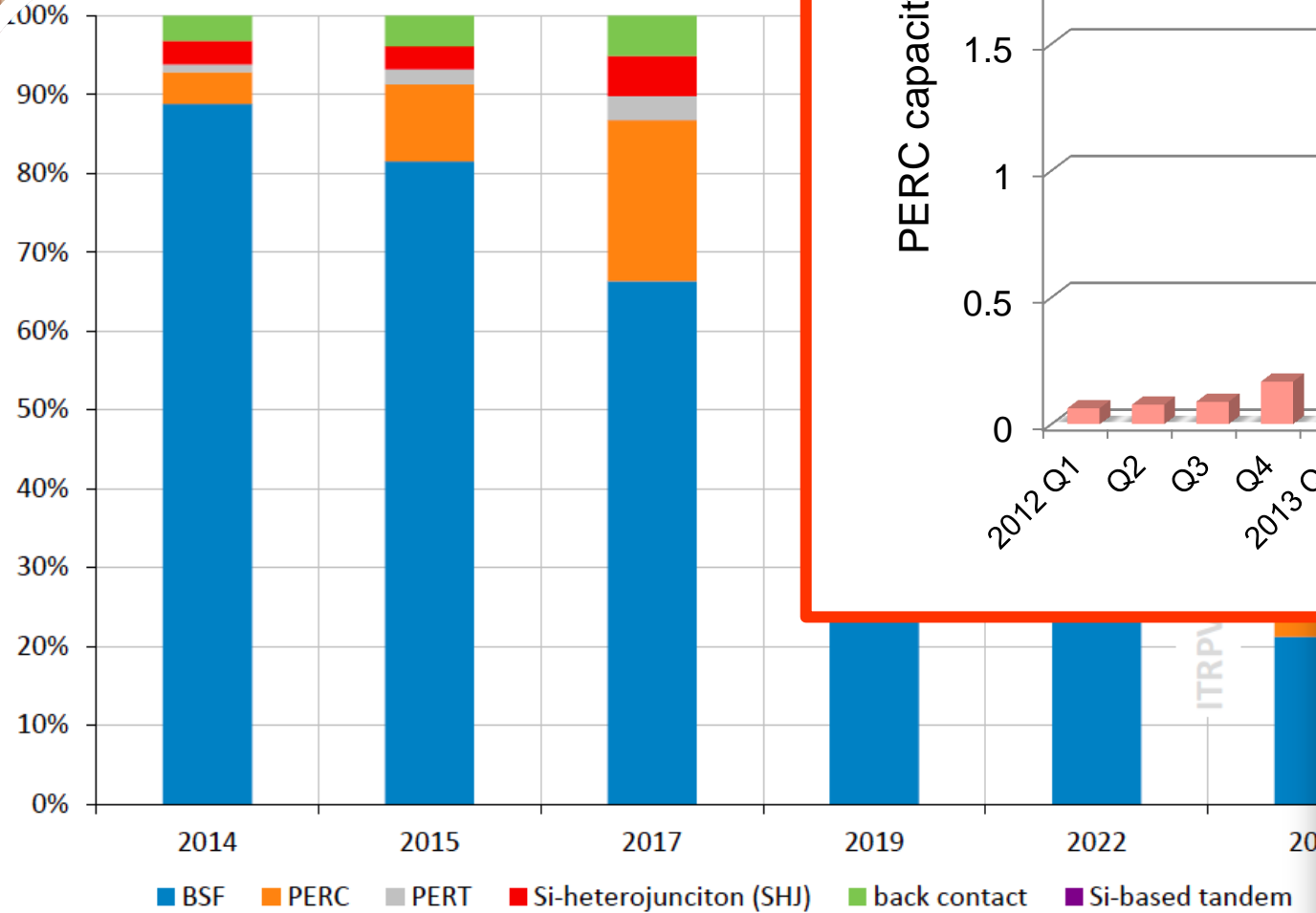
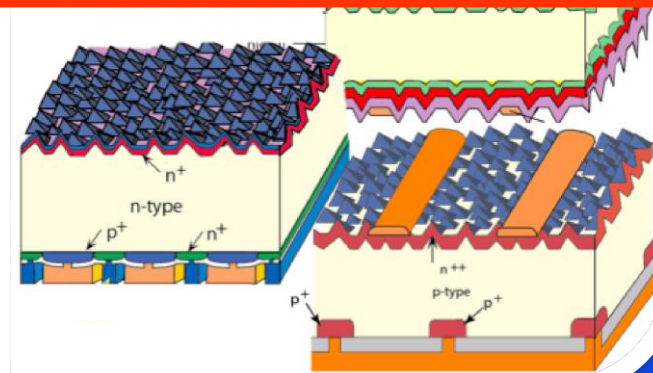
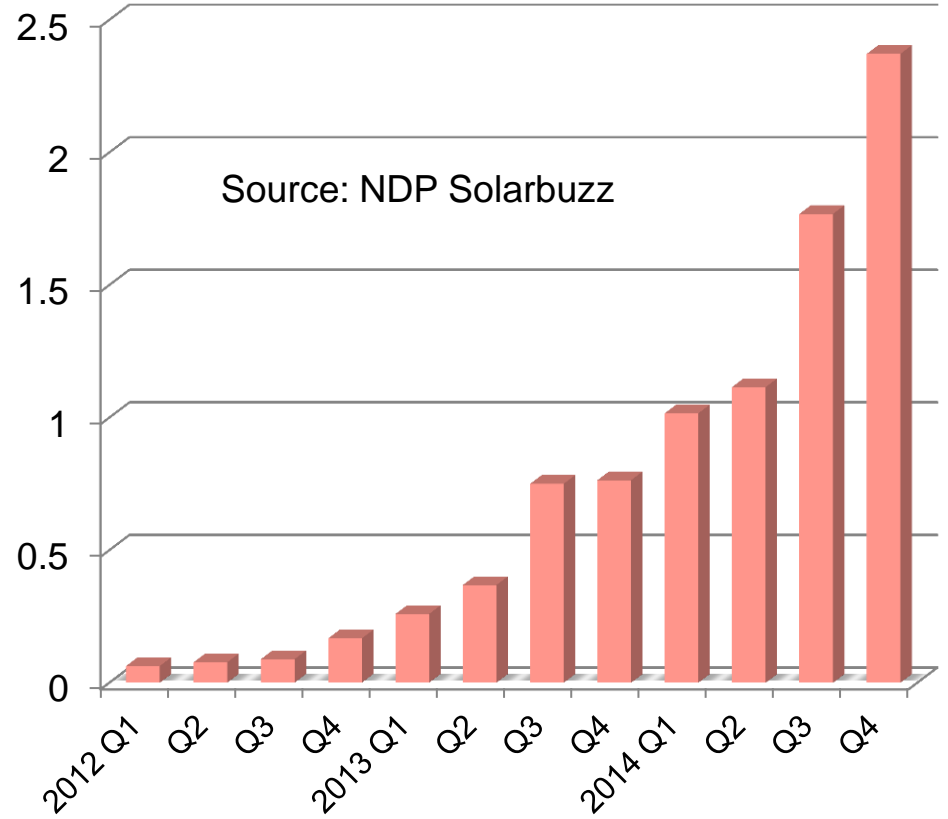


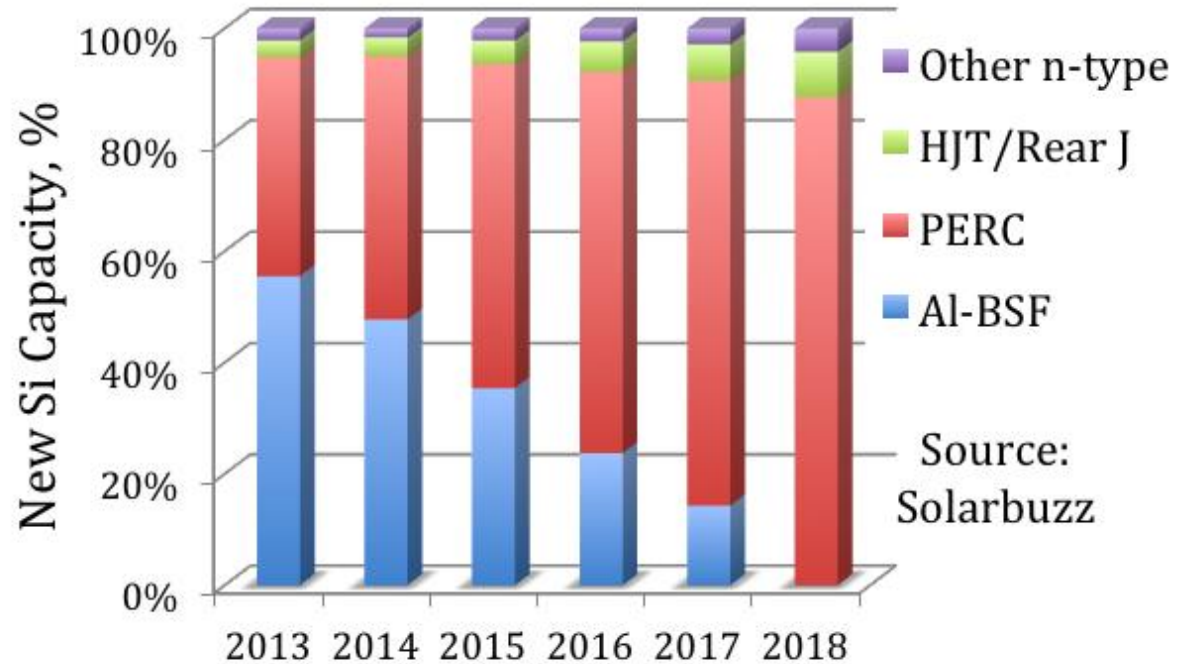
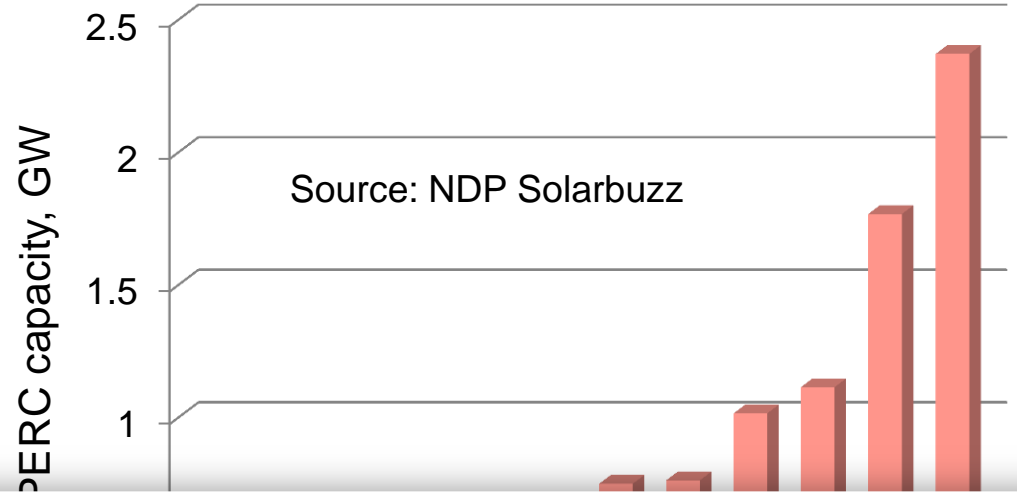
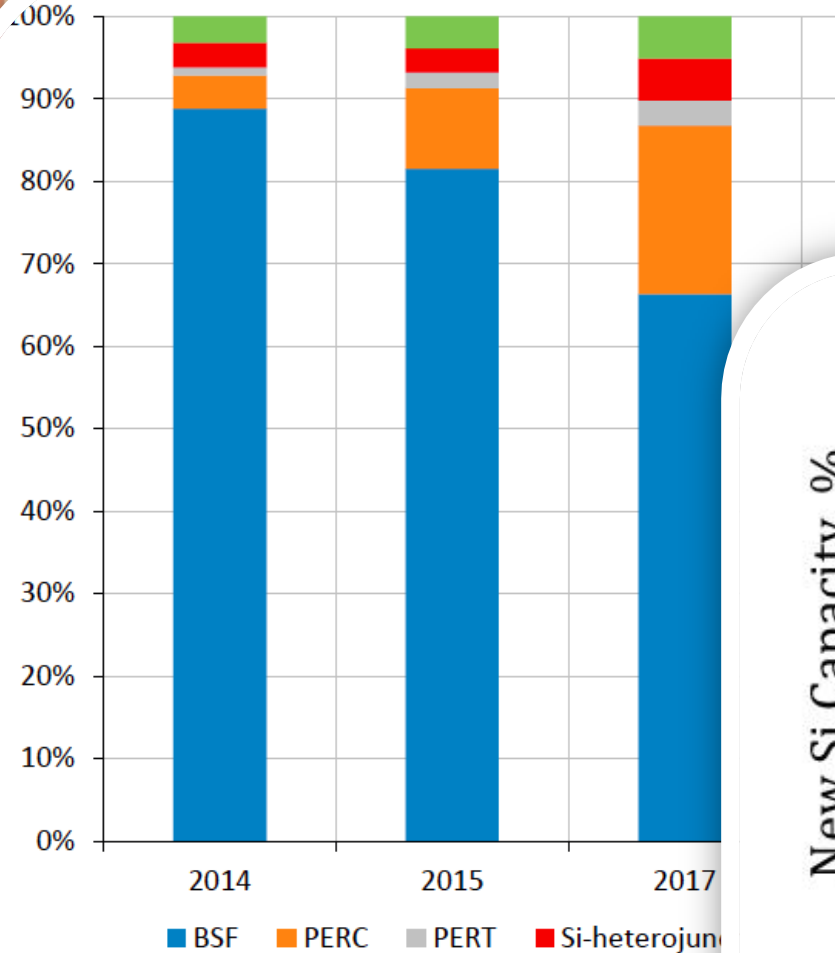
Fig. 28
Worldwide market shares for different cell technologies.

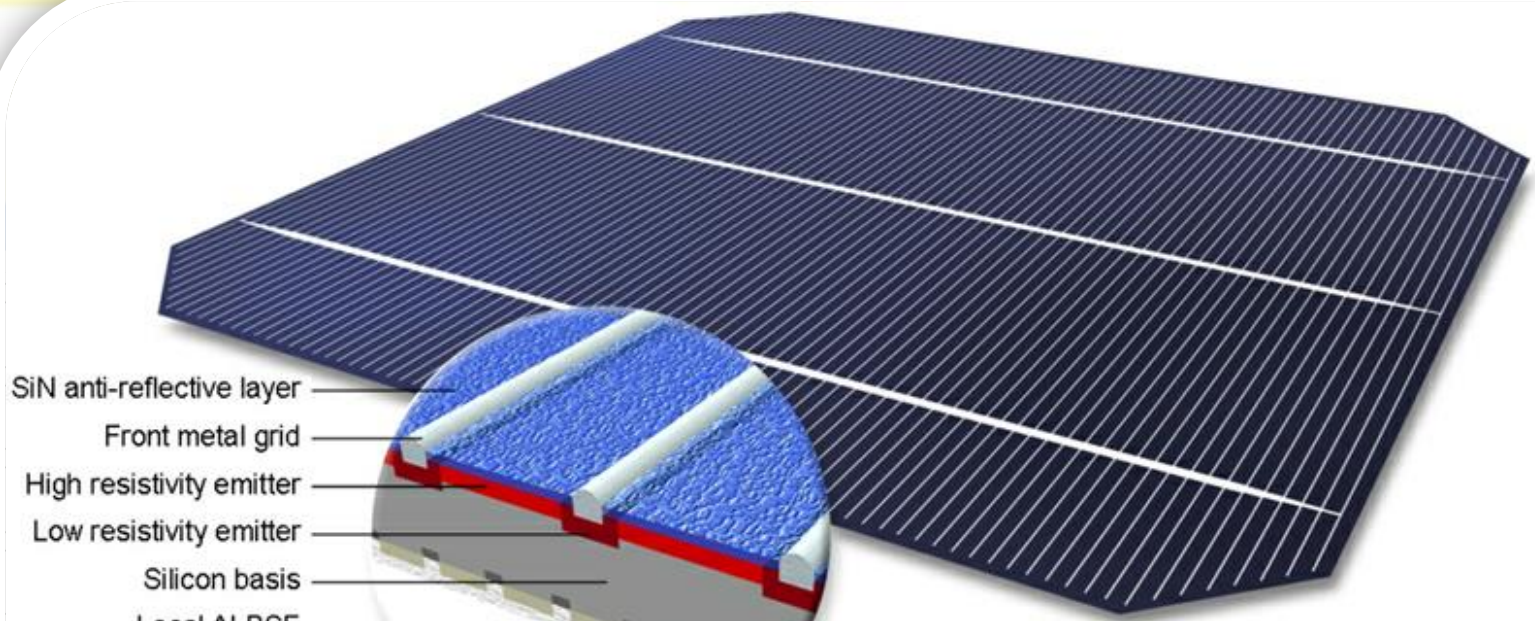




PERC capacity, GW

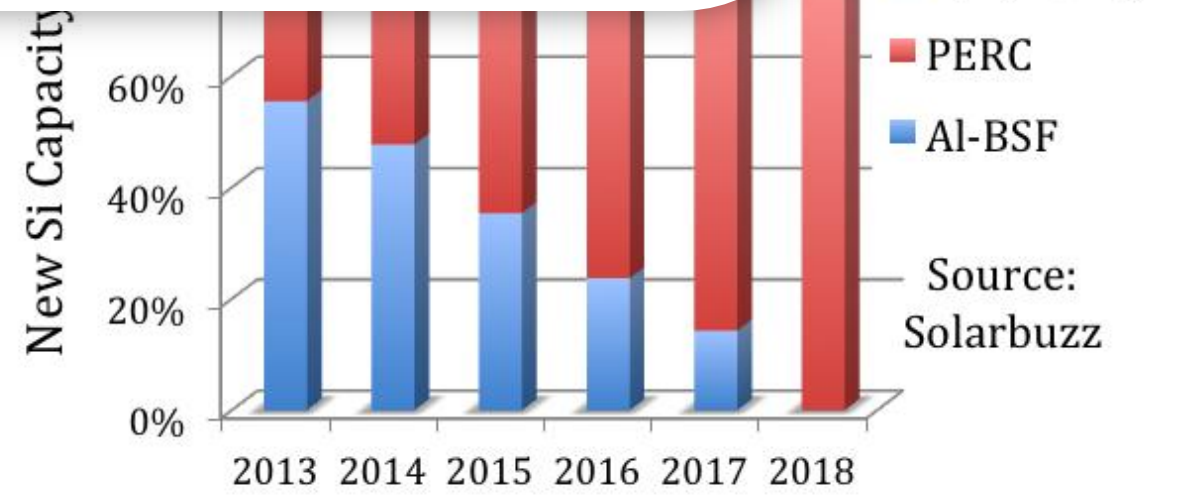
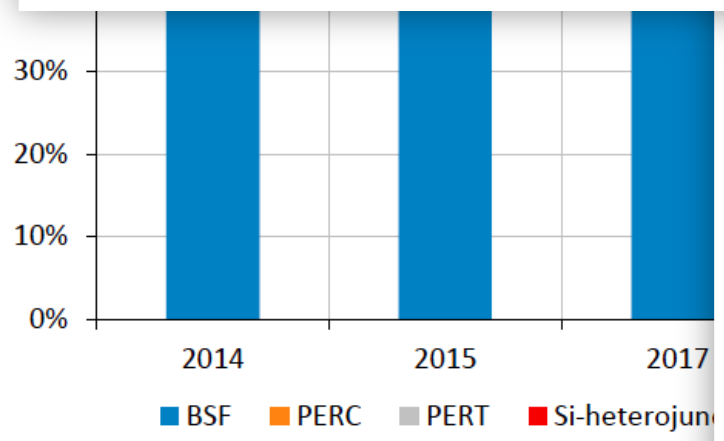
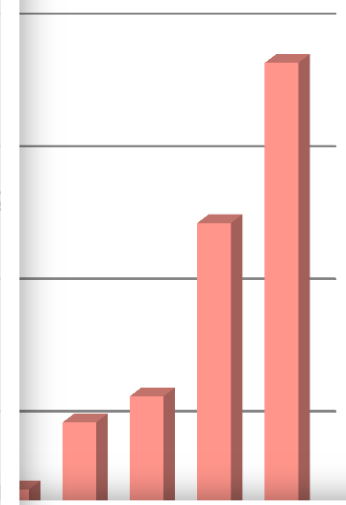






- SiN anti-reflective layer
- Front metal grid
- High resistivity emitter
- Low resistivity emitter
- Silicon basis
- Local Al-BSF
- Dielectric layer

centrotherm



Source: Solarbuzz

Cell technology

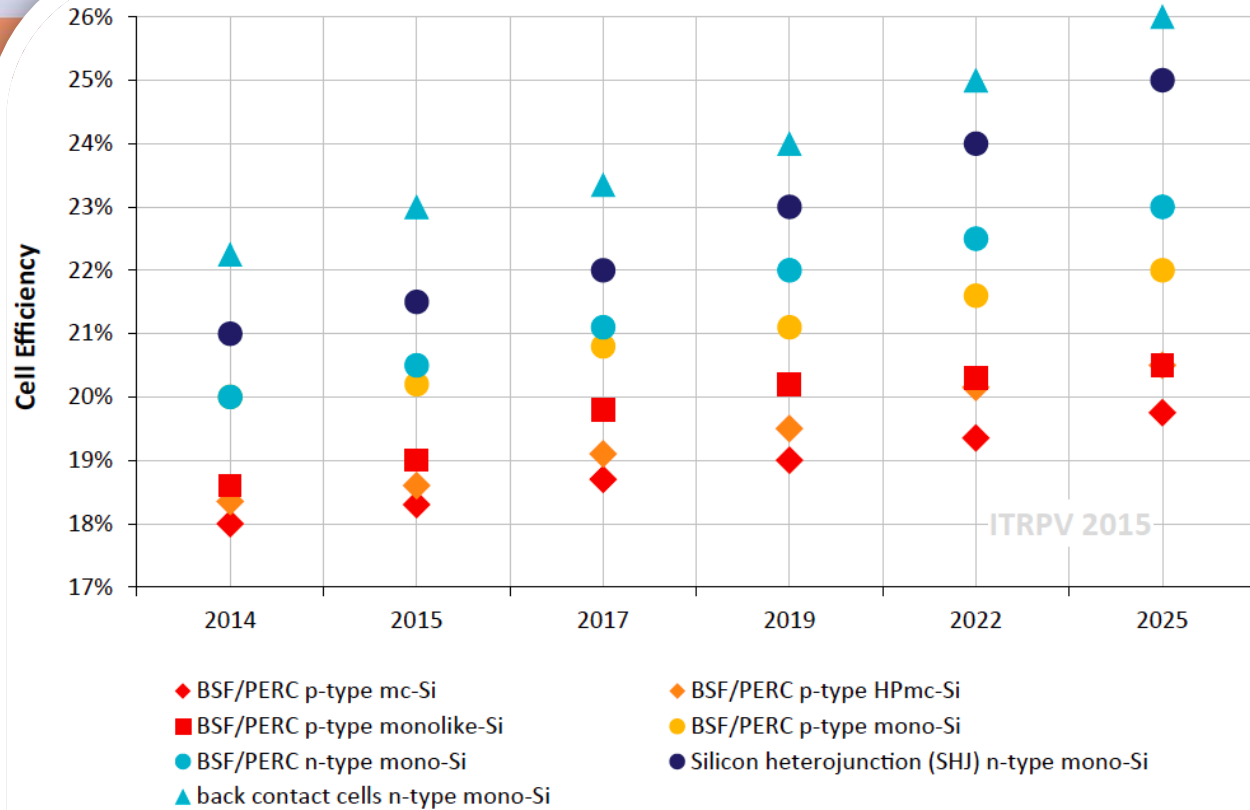


Fig. 26

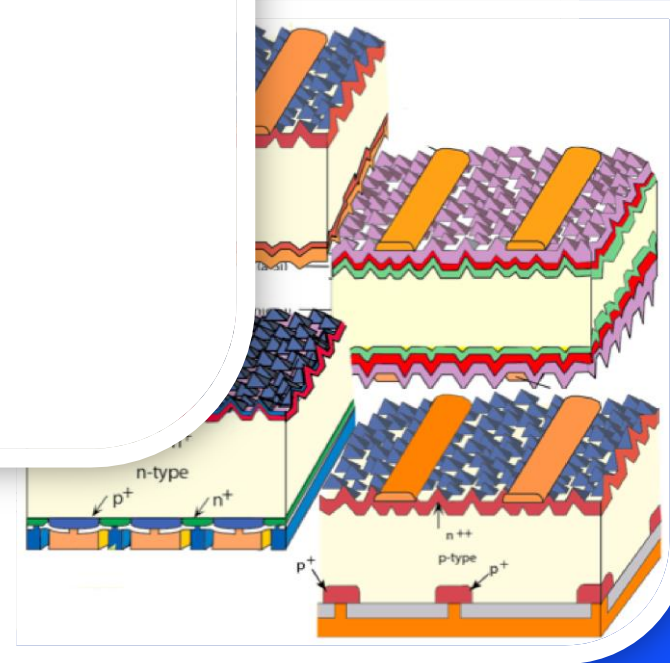
Average stabilized efficiency values for Si solar cells (156x156mm²).

8
s for different cell
ologies.

ITRPV 2015

2014 2015 2017 2019 2022 2025

■ BSF ■ PERC ■ PERT ■ Si-heterojunction (SHJ) ■ back contact ■ Si-based tandem



Cell technology

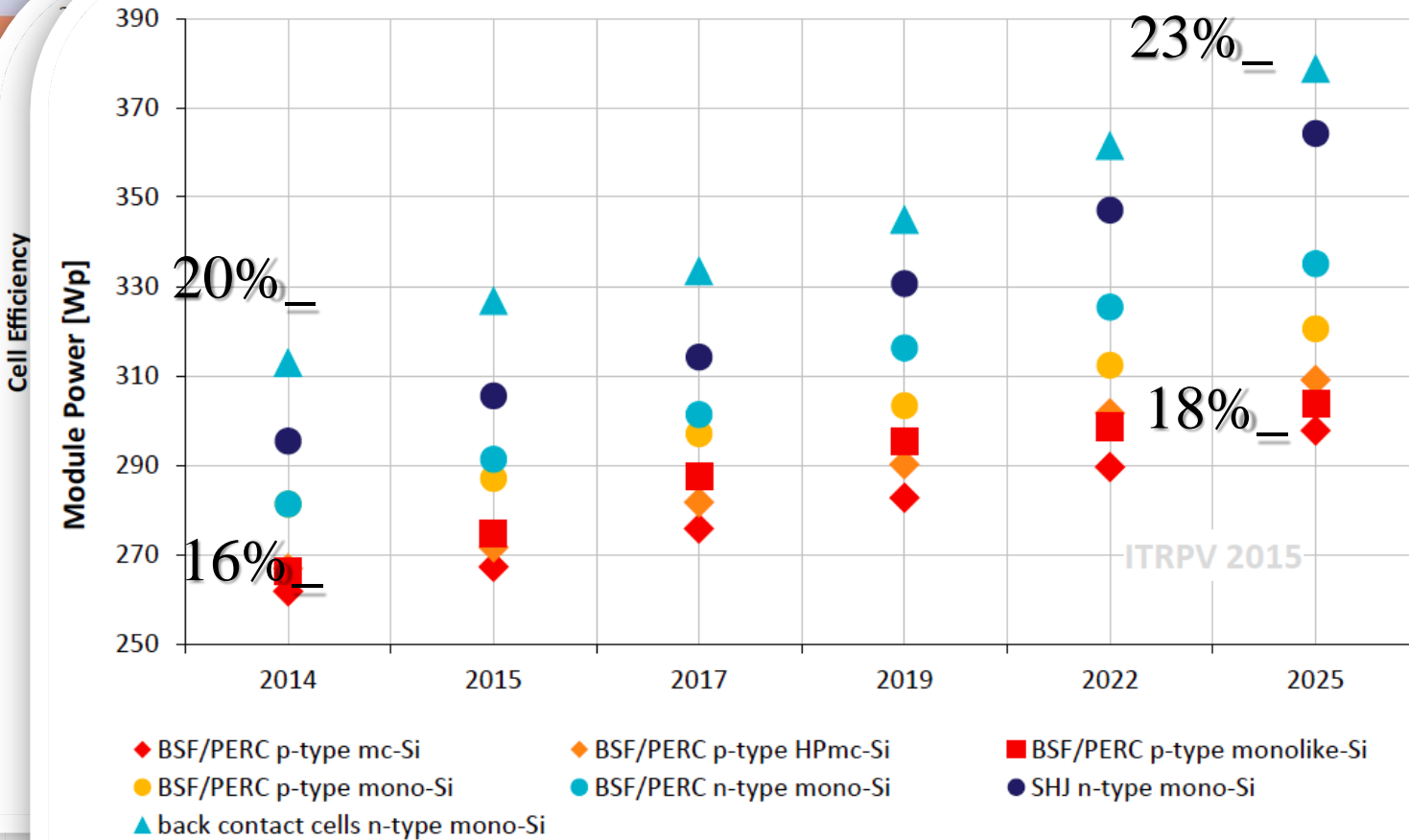
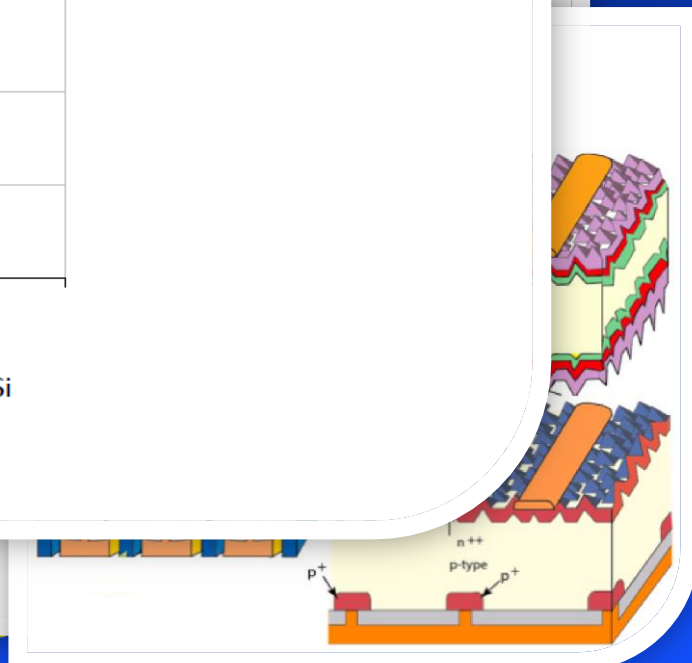


Fig. 27
 Predicted trend curve for module power for different c-Si cell types.

■ BSF
 ■ PERC
 ■ PERT
 ■ Si-heterojunction (SHJ)
 ■ back contact
 ■ Si-based tandem



Encapsulant

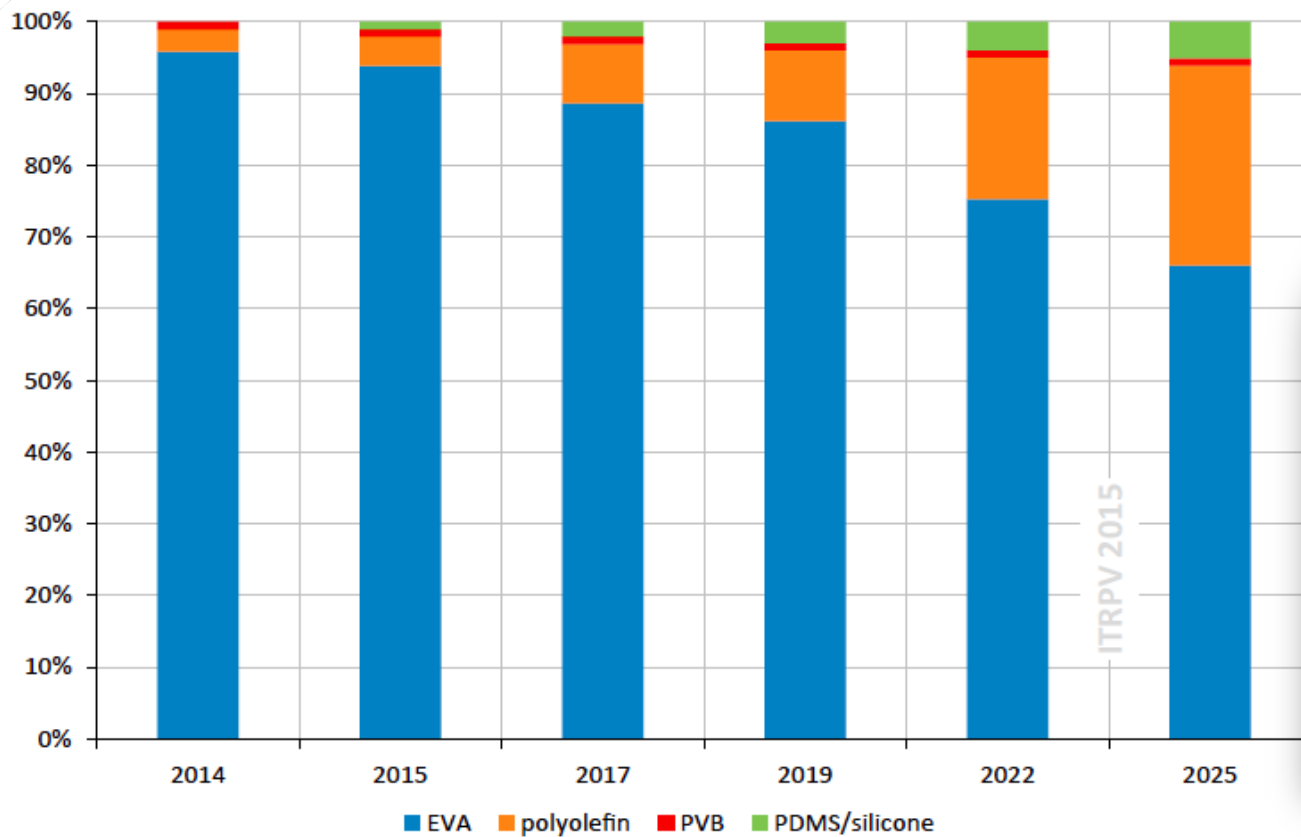
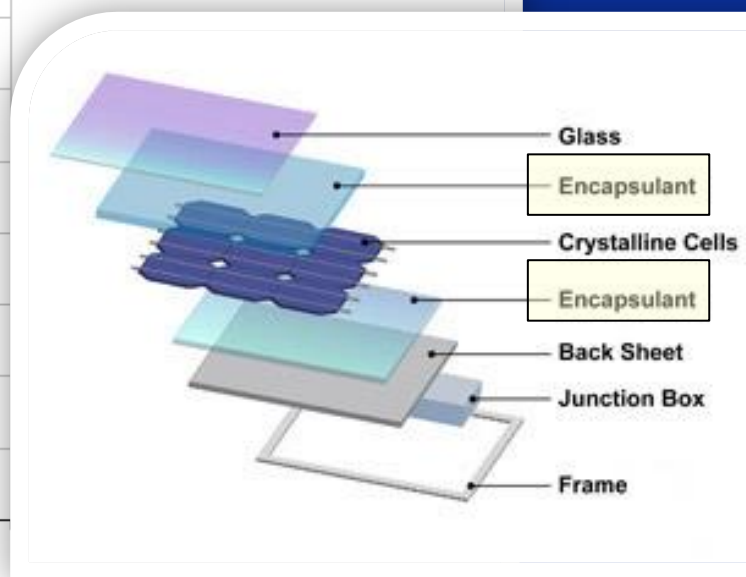
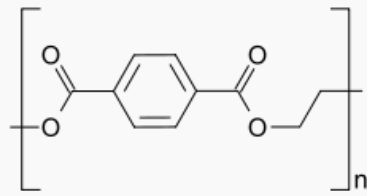
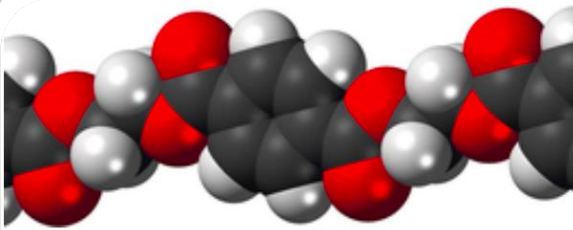


Fig. 10
Expected market shares for different encapsulation materials.





Backsheets

Model of a section of the polyethylene terephthalate polymer (PET).
Photo: Wikipedia/Jynto

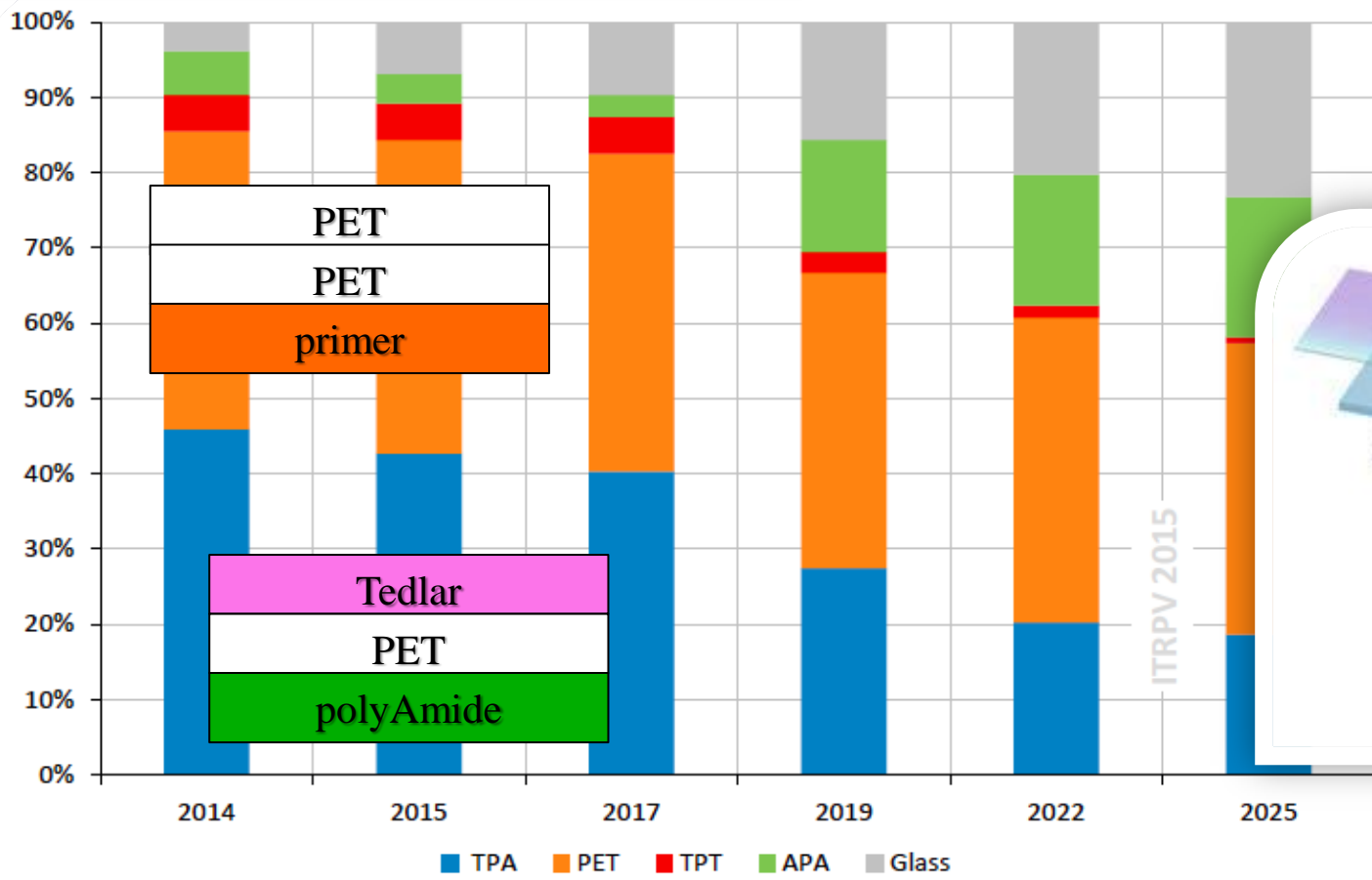
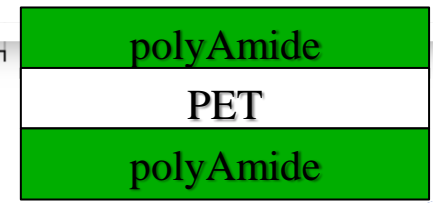
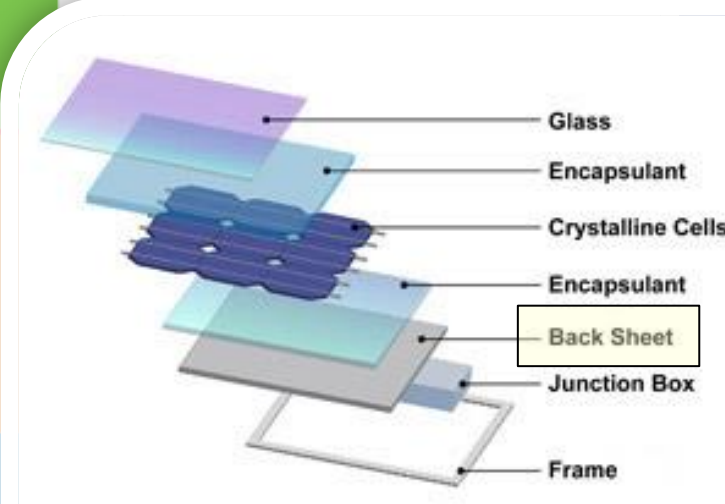


Fig. 11
Market shares for different module backsheet materials.



Learning curve

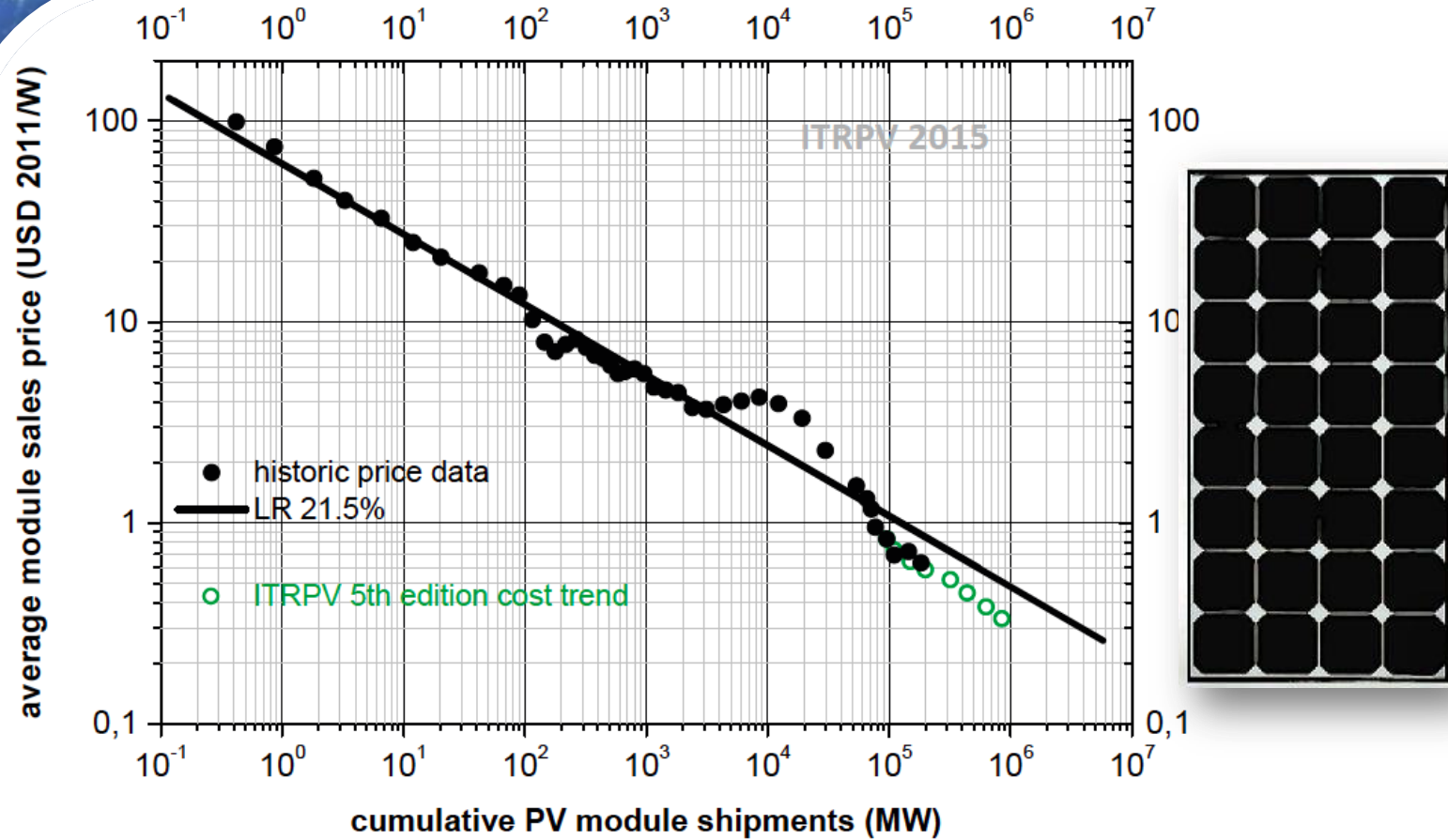


Fig. 36 Learning curve of module price as a function of cumulative PV module shipments with historic price data and the ITRPV 5th edition cost trend shown in Table 3.

International Technology Roadmap for Photovoltaic

2014 Results

April 2015

System Costs

Sixth

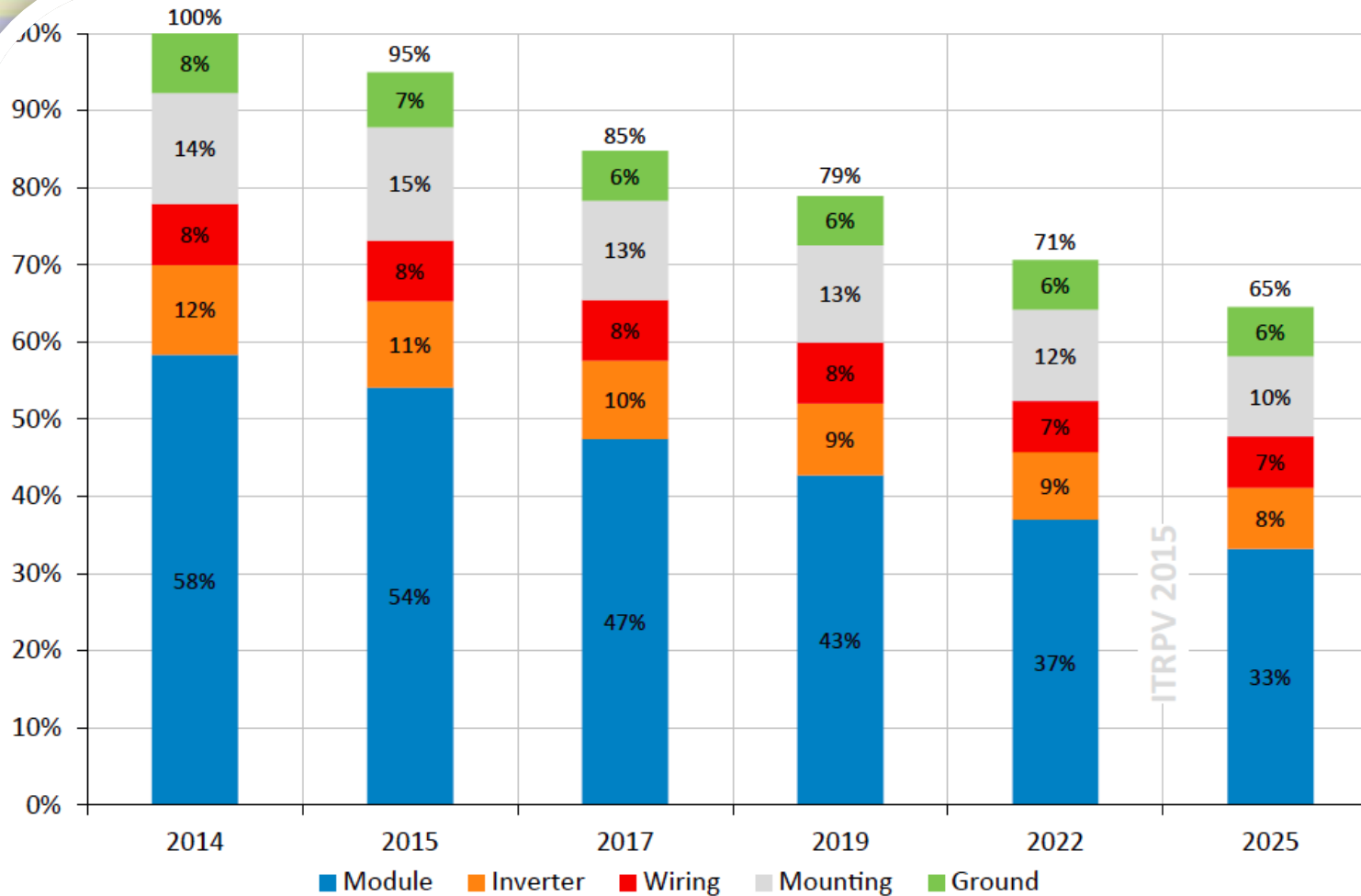


Fig. 33
 Relative system cost development for systems > 100kW in the U.S. and Europe (2014 = 100%).



Levelised Cost of Electricity

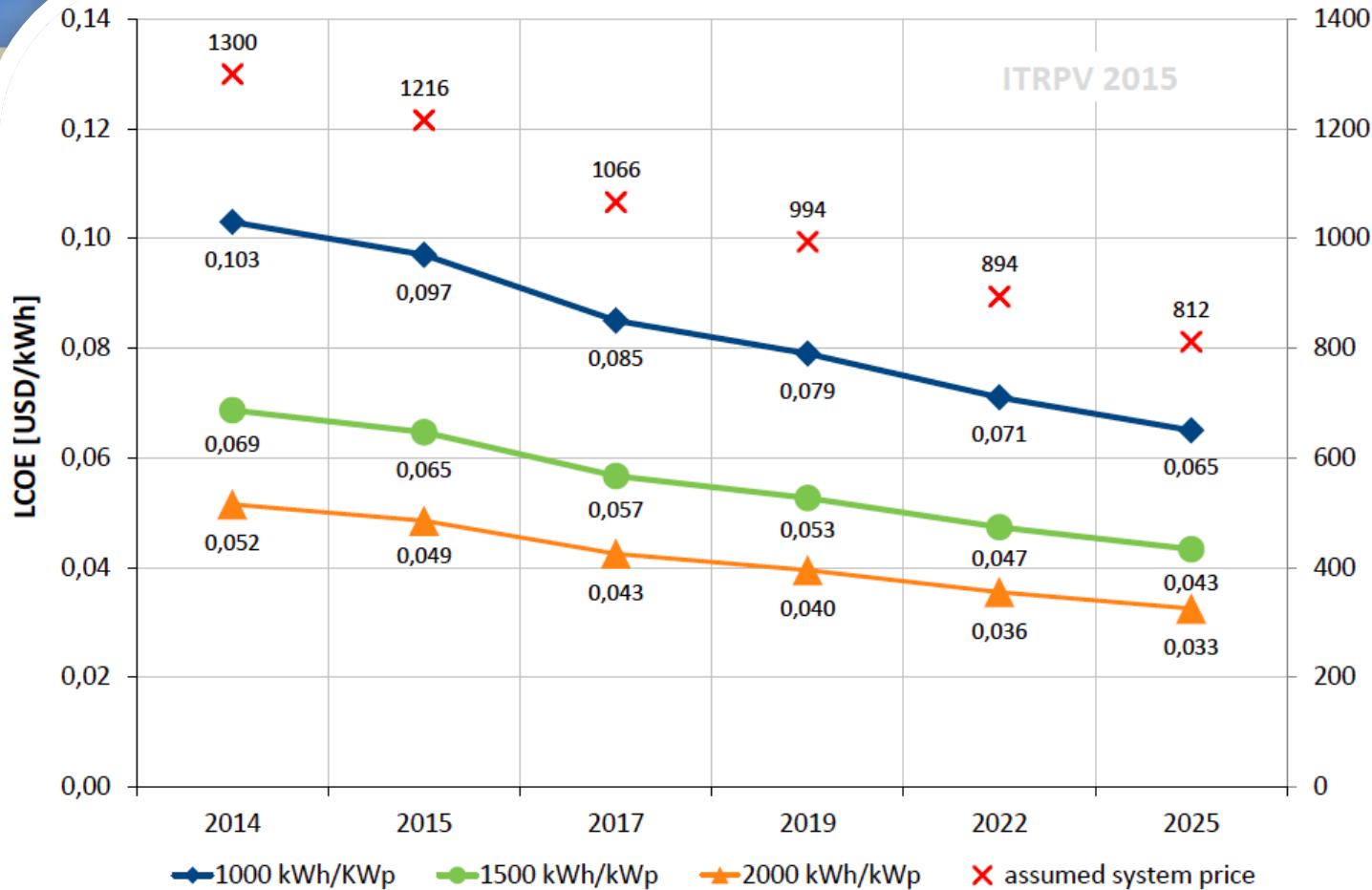


Fig. 35
 Calculated LCOE values for different insolation conditions. Financial conditions: 80% debt, 5%/a interest rate, 20-year loan tenor, 2%/a inflation rate, 25 years usable system service life.





ACAP

Summary



- . *Poly shift to fluidised bed (FBR)*
- . *Ingots bigger, continuous CZ (other dopants!)?*
- . *Wafer thickness reduction on back burner*
- . *Sheet rho increase slower than expected*
- . *Move from Al-BSF after 30 years (to PERC/PERL/PERT)*
- . *Move from Tedlar to PET backsheets*
- . *Ongoing cost reductions*
(poly, wafers, modules, systems – 5%/year)

UNSW



Australian Centre for Advanced Photovoltaics



Thank you!

ARENA



Australian Government

**Australian Renewable
Energy Agency**