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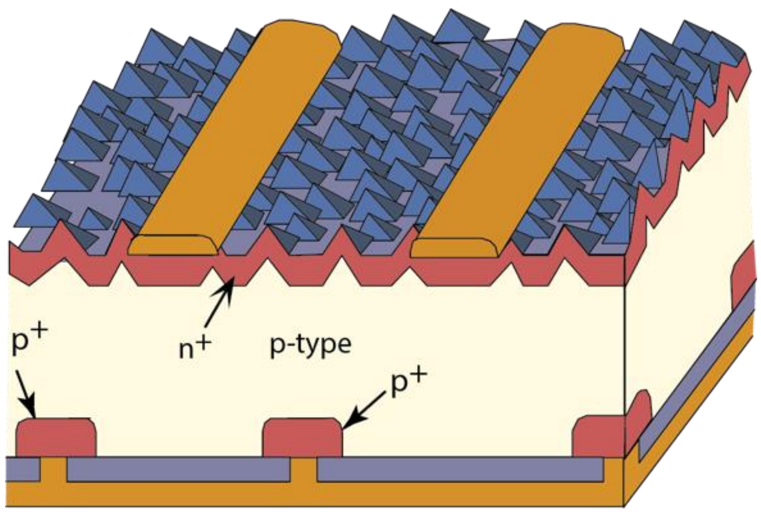
Australia's
Global
University

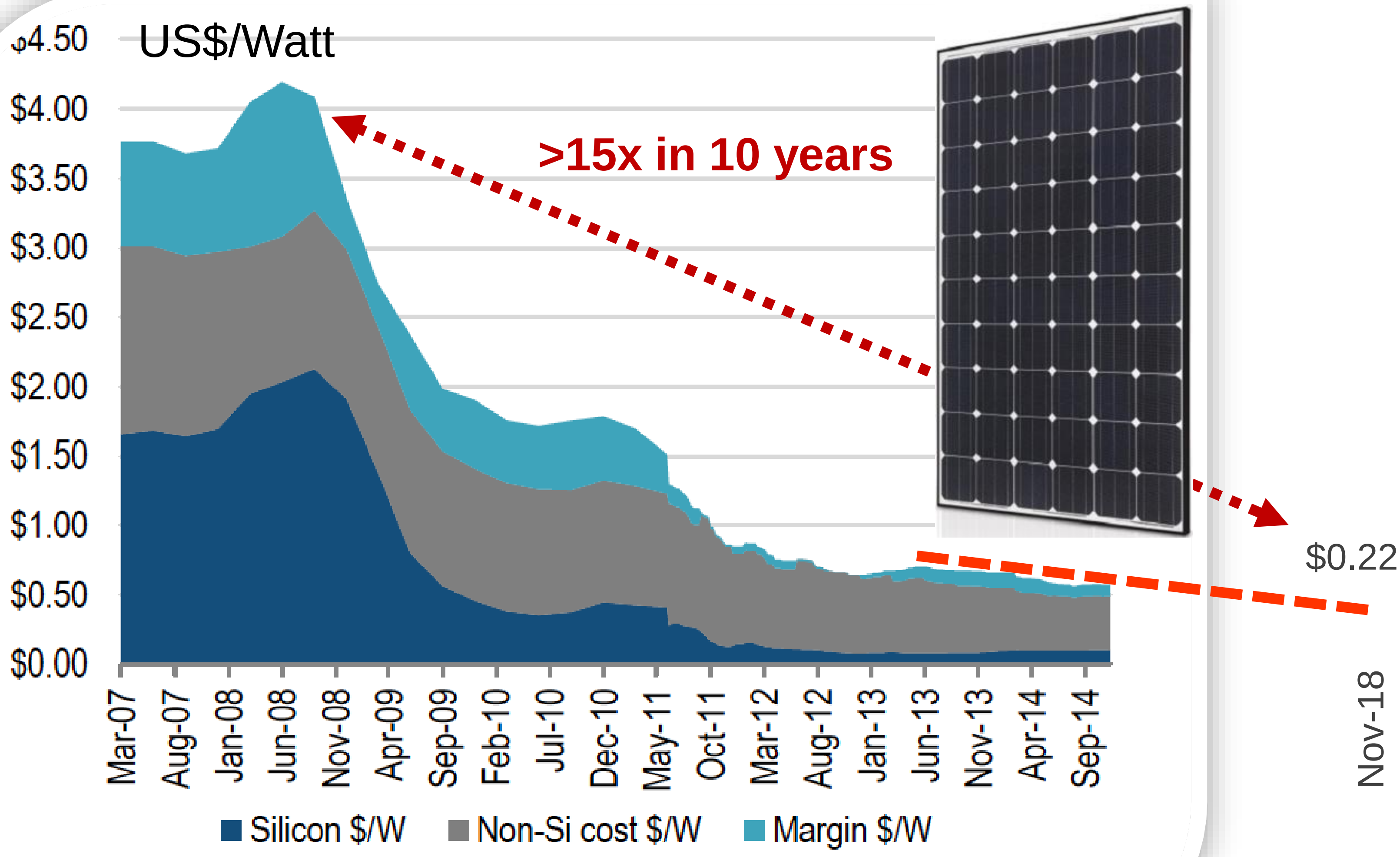
"What's next in photovoltaics, beyond PERC?"

Martin A. Green, UNSW Sydney

ARENA
Australian Government
Australian Renewable
Energy Agency



Recent cost reductions



Source: EnergyTrend, Company data, Credit Suisse estimates.

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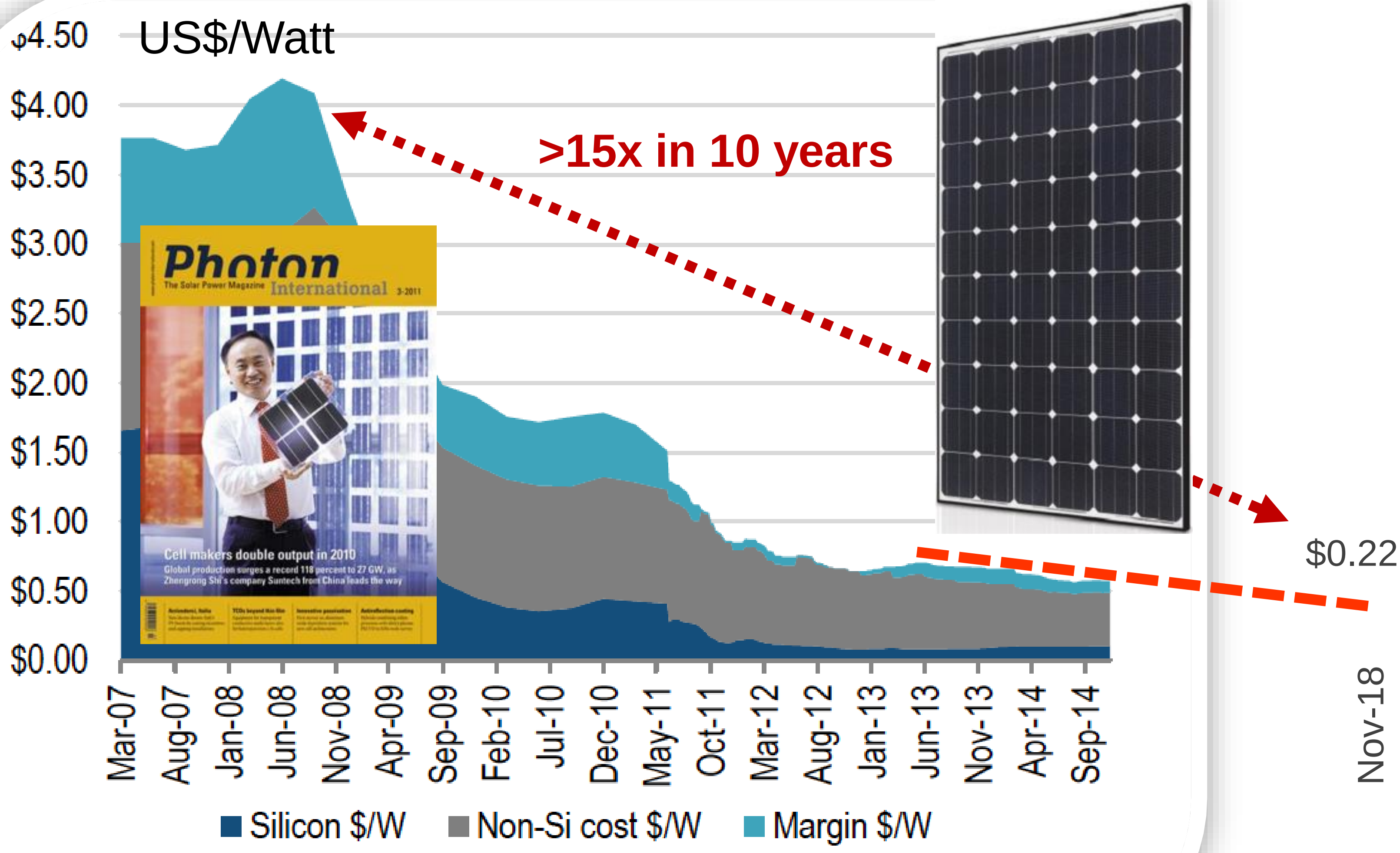

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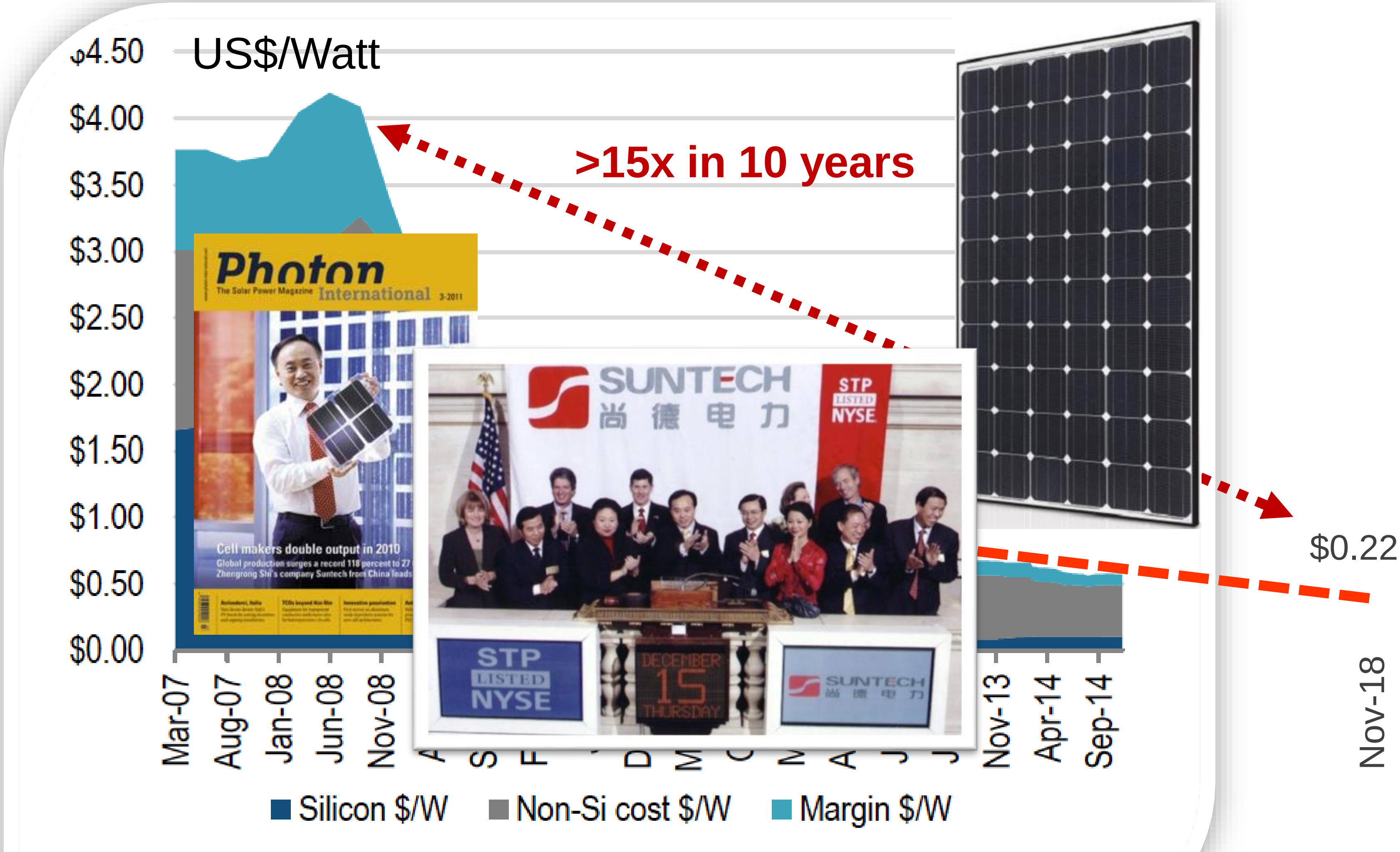

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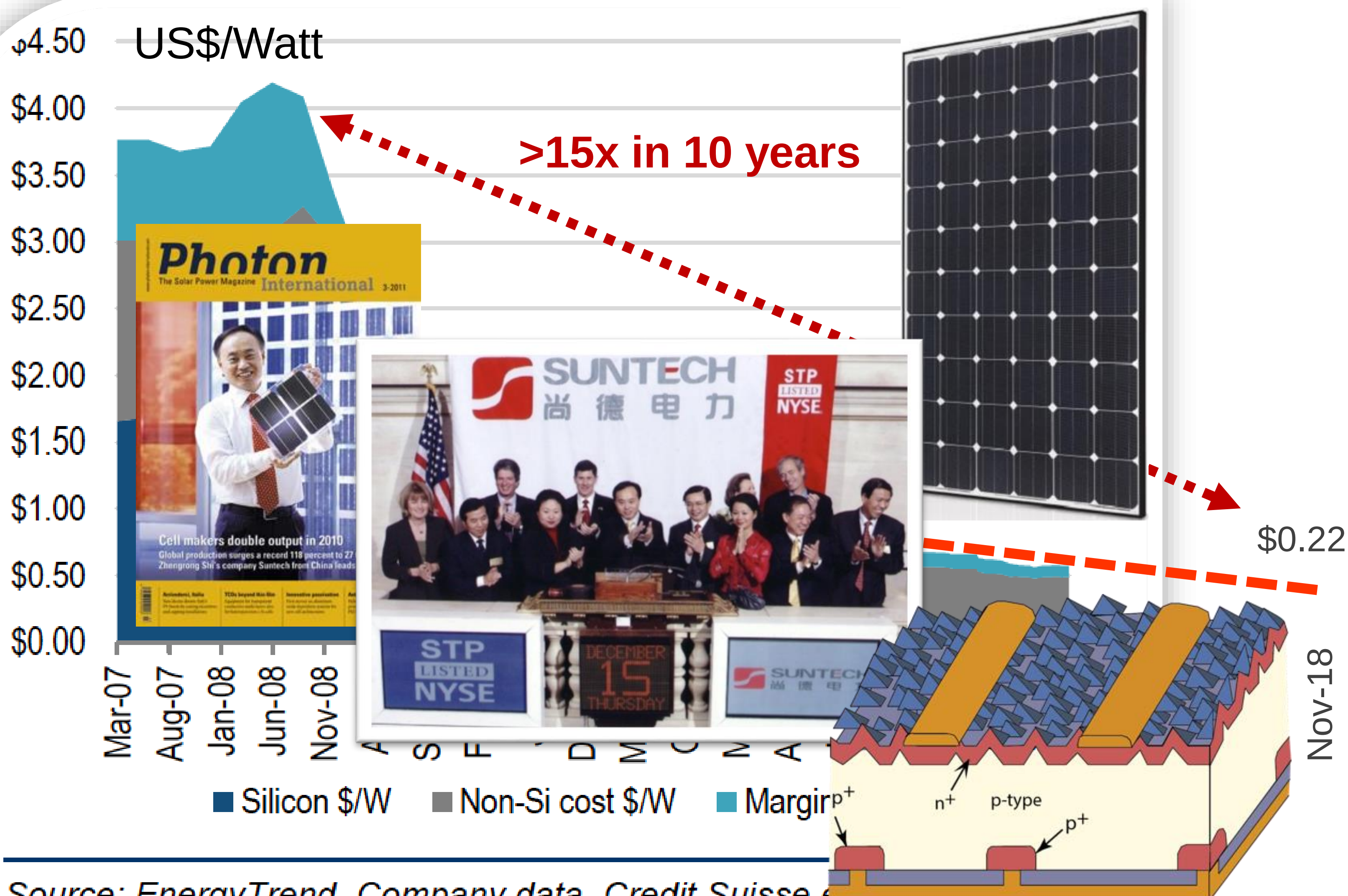

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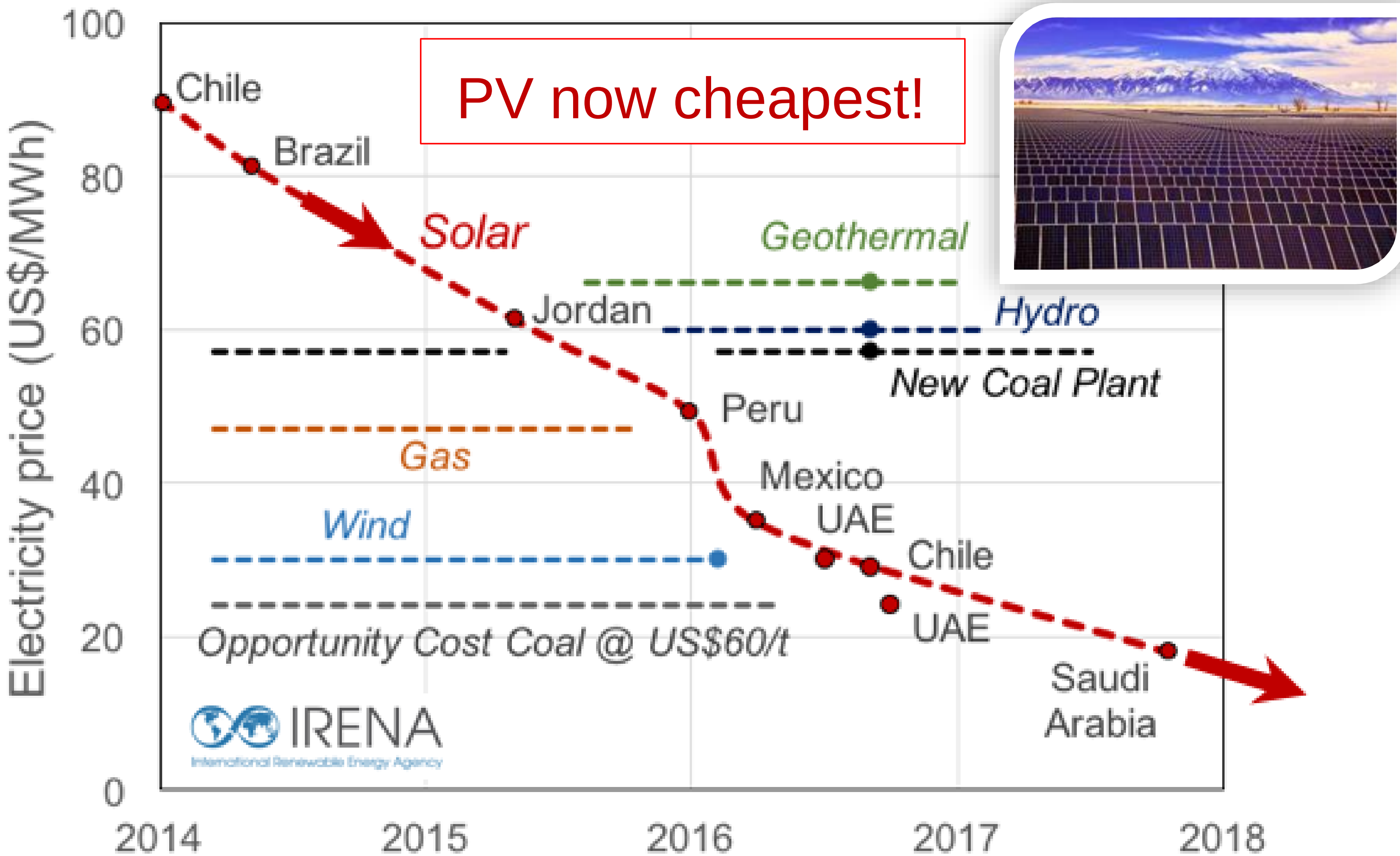
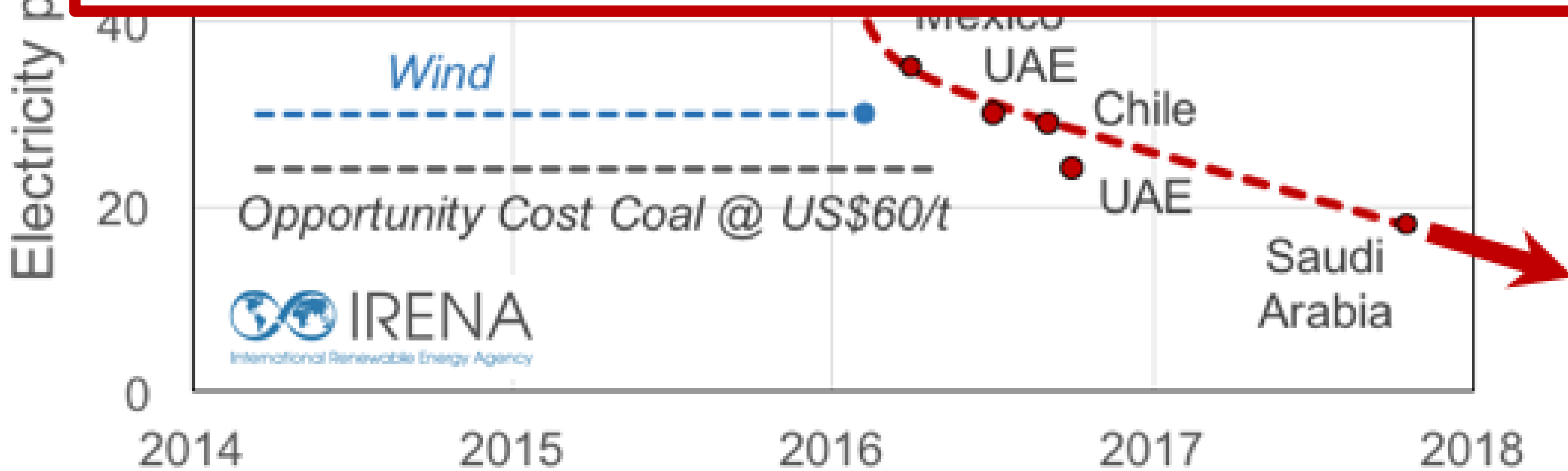
Low Bids: International Electricity Auctions



Carbon Tracker Initiative

The myth of cheap coal– 35% of coal capacity costs more to run than building new renewables in 2018, increasing to 96% by 2030



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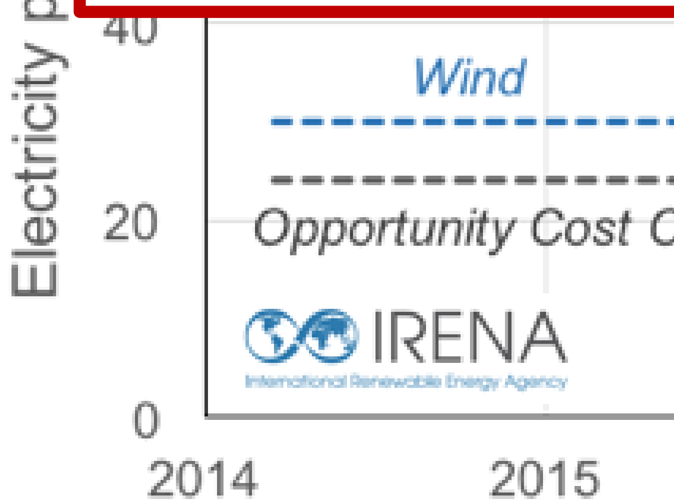
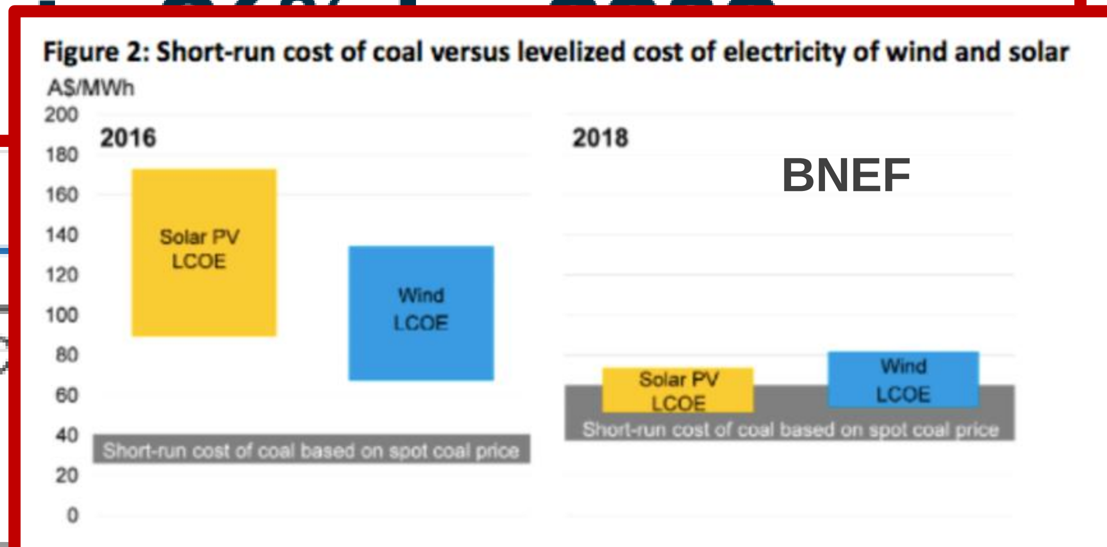
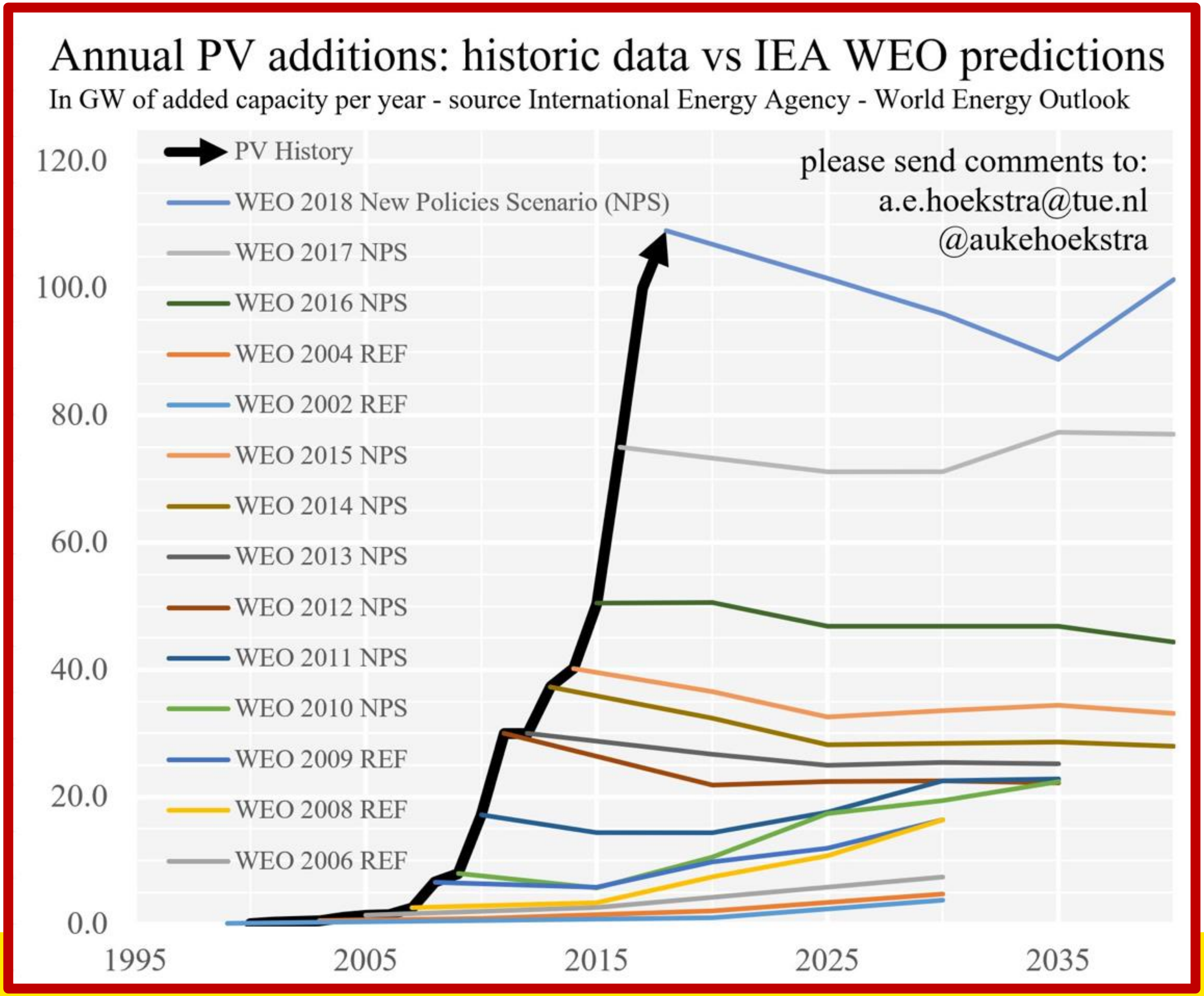




PV market growing quickly (> 0.1 TW in 2017)



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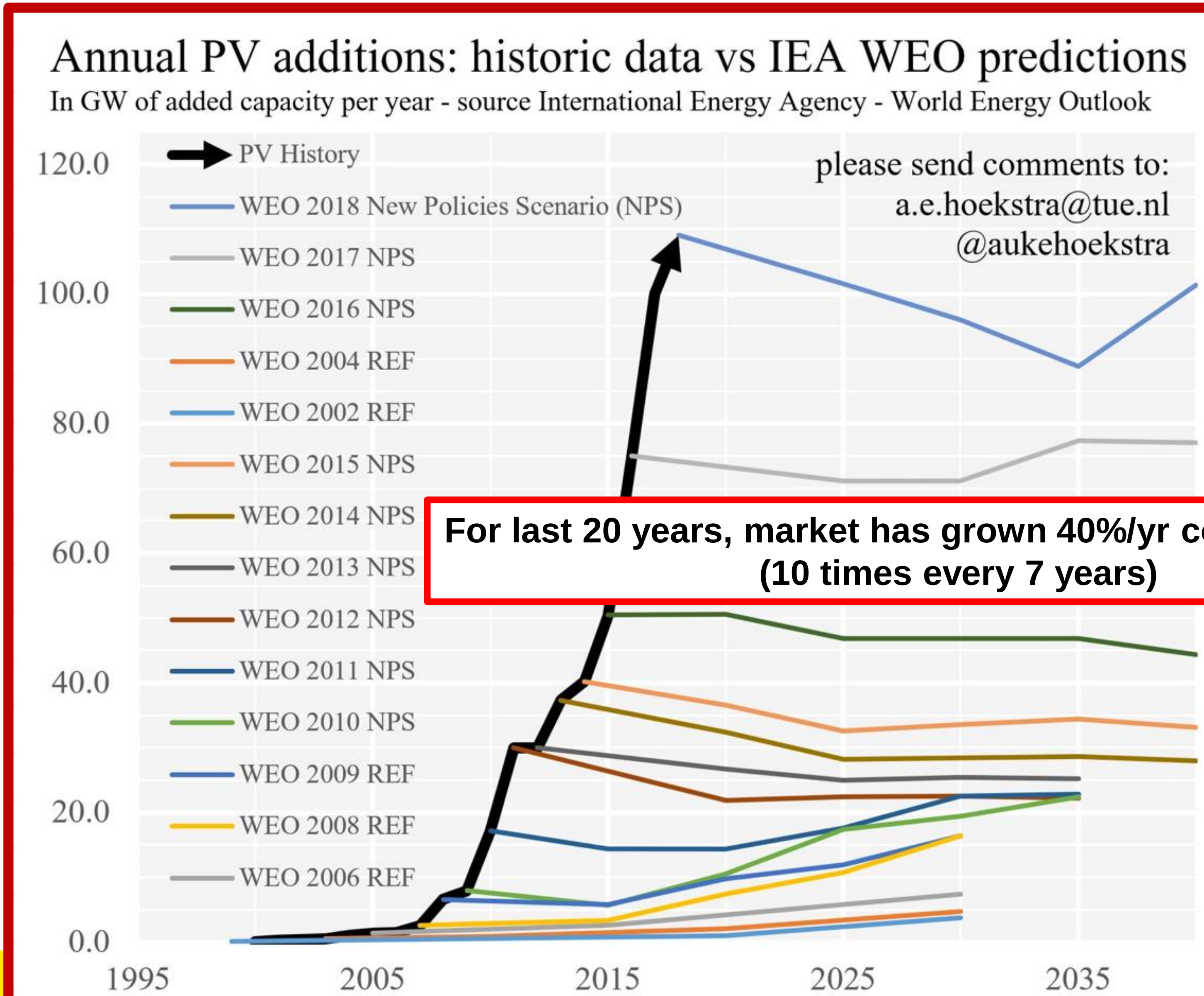
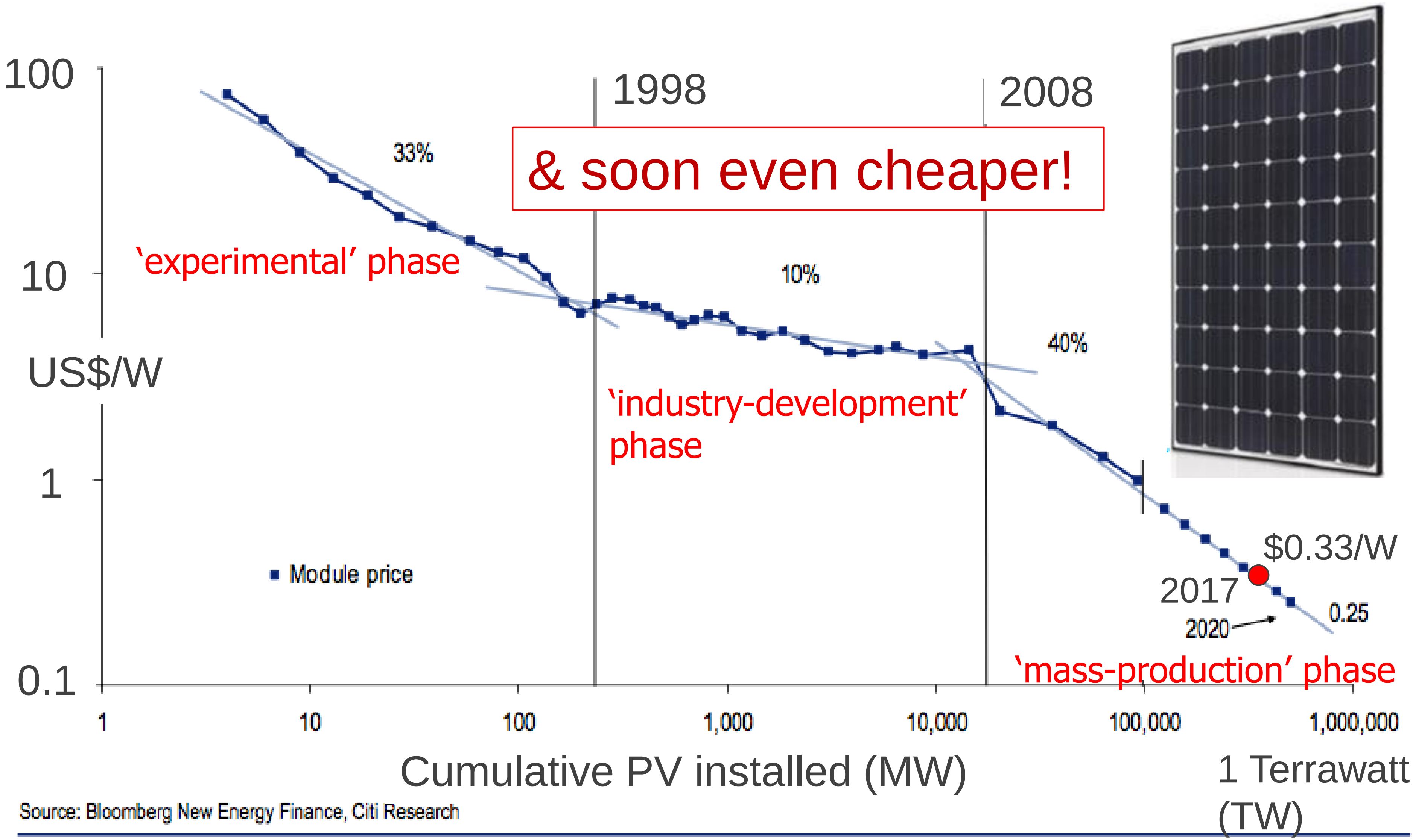
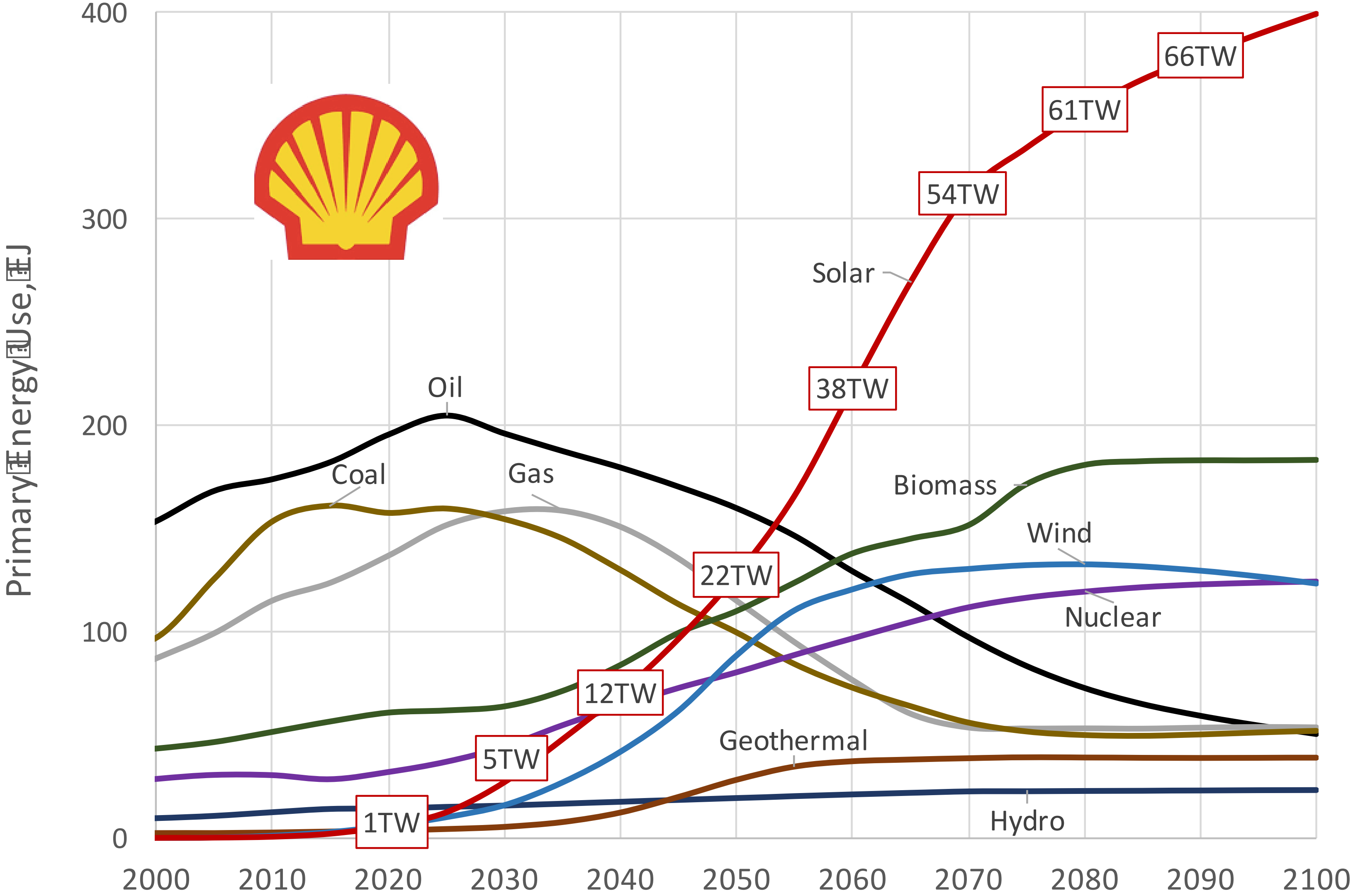


For last 20 years, market has grown 40%/yr compounded!
(10 times every 7 years)

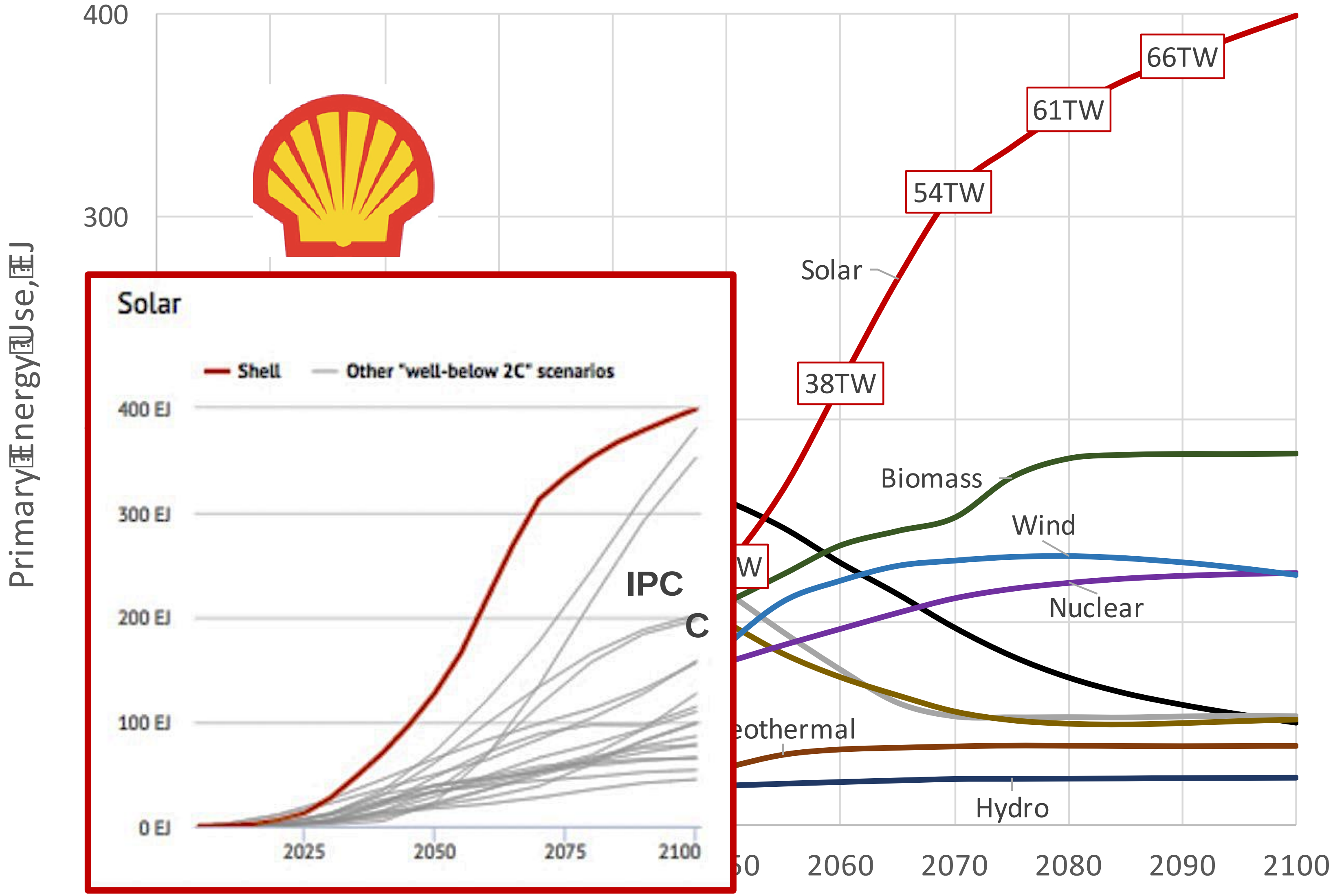

& soon even cheaper!
100
10
1
0.1
US$/W
1998
2008
33%
10%
40%
'experimental' phase
'industry-development' phase
'mass-production' phase
Module price
$0.33/W
2017
2020
0.25
1
10
100
1,000
10,000
100,000
1,000,000
Cumulative PV installed (MW)
1 Terrawatt (TW)
Source: Bloomberg New Energy Finance, Citi Research

Primary energy use in Shell's "Sky" scenario (26 March 2018)



Includes waste energy oil, coal, gas, bioenergy, nuclear; only generated energy wind, solar

Primary energy use in Shell's "Sky" scenario (26 March 2018)



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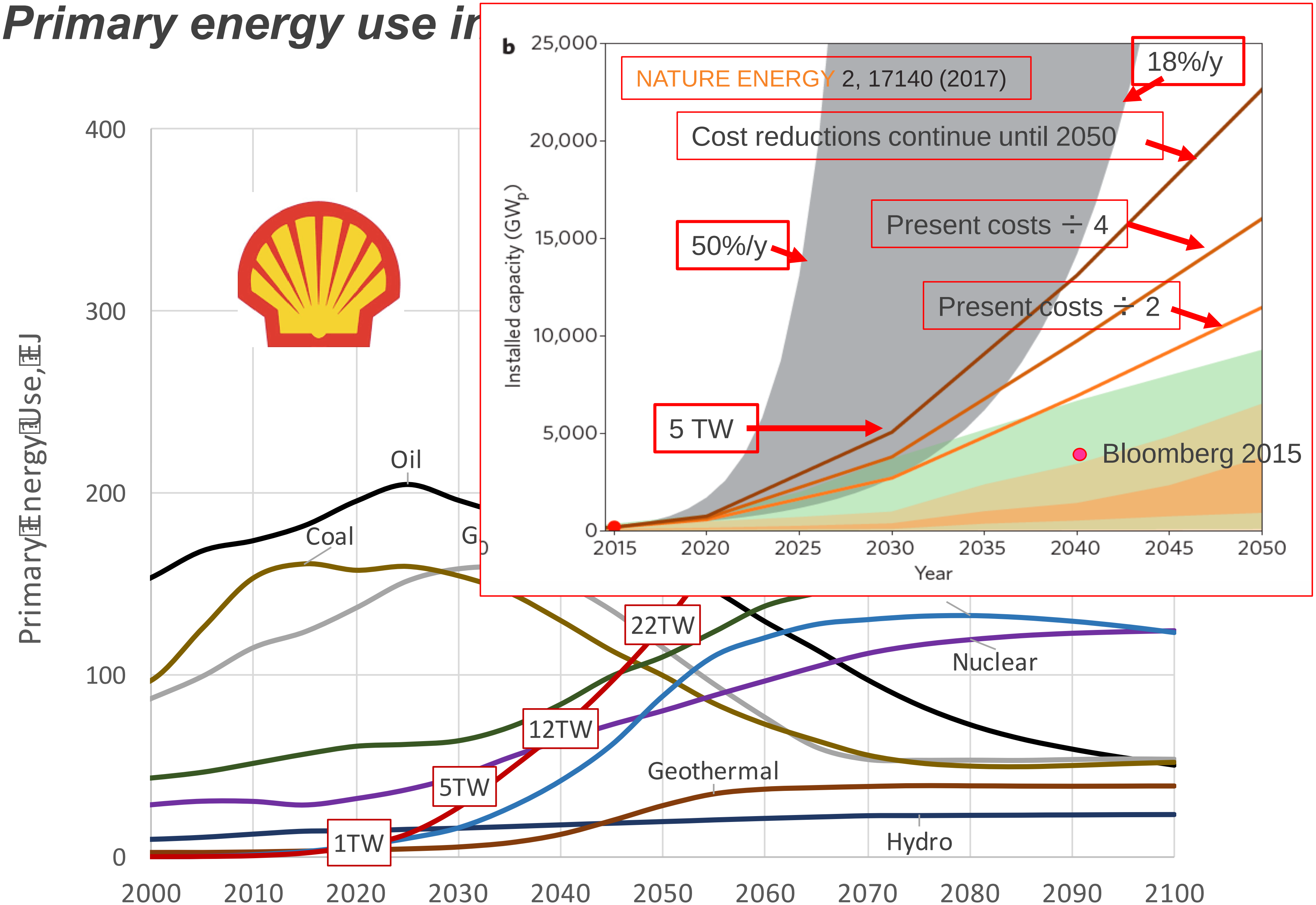
Primary energy use in



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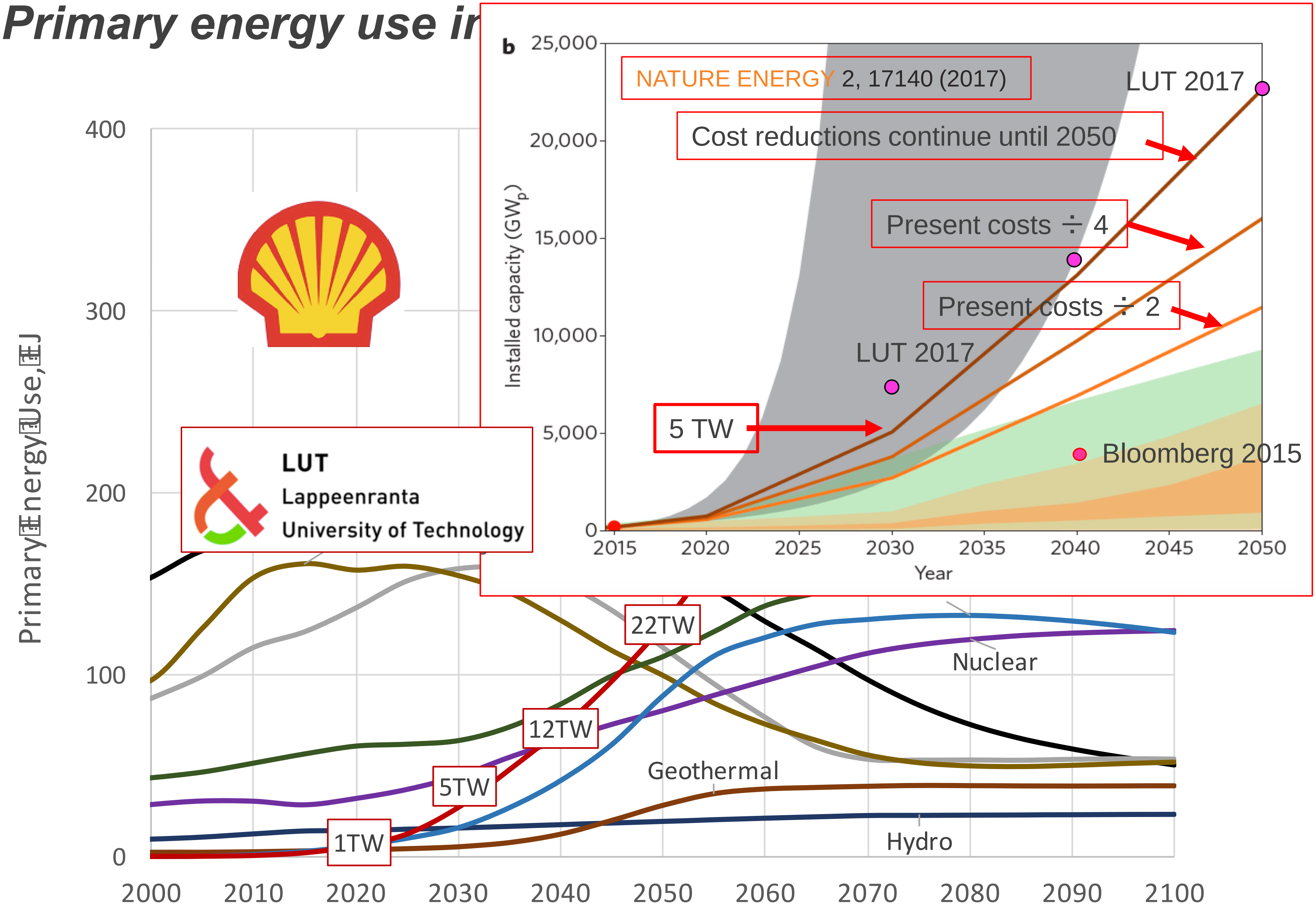
Primary energy use ir



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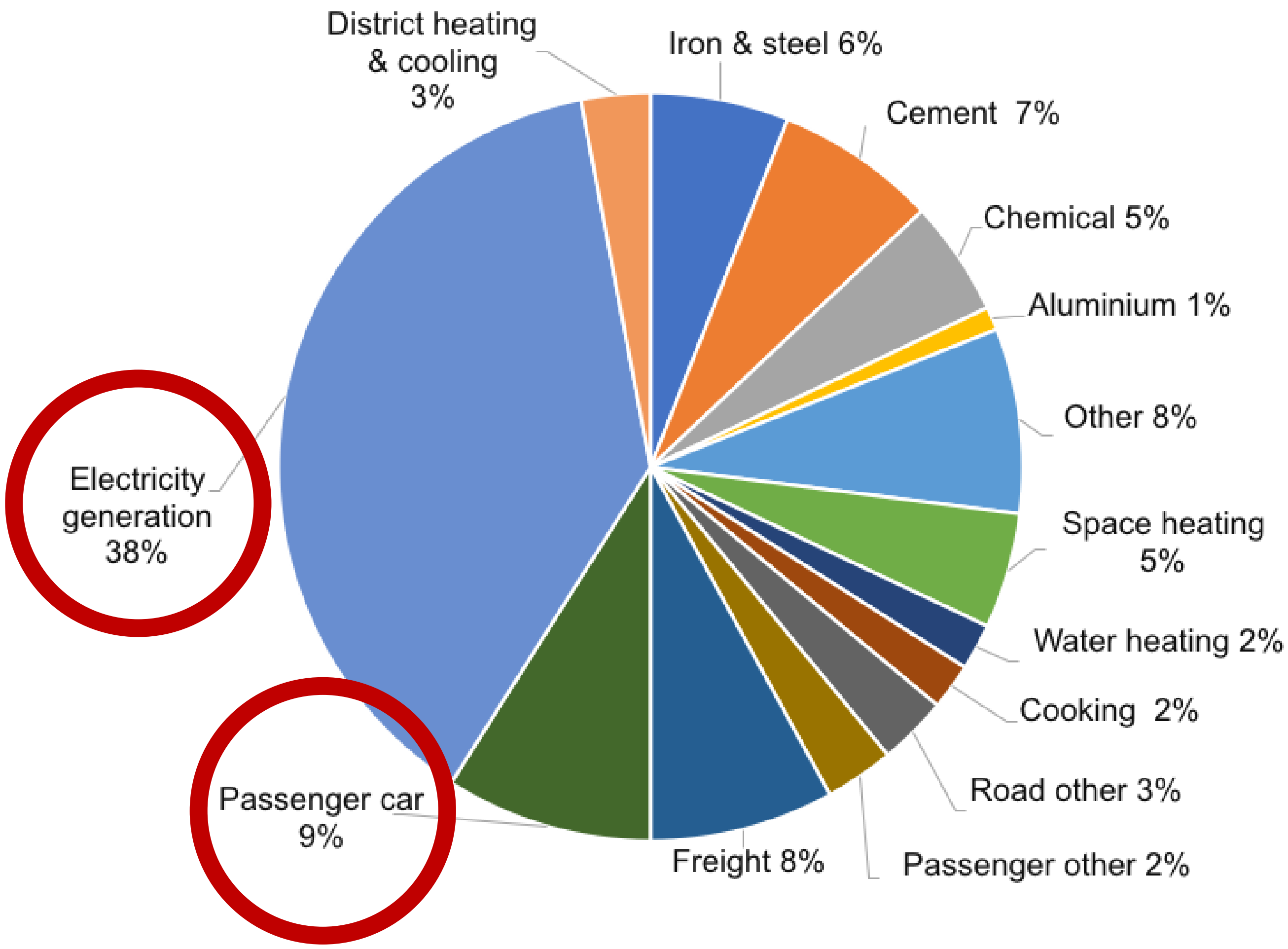
Source of global CO_2 emissions



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International Renewable Energy Agency

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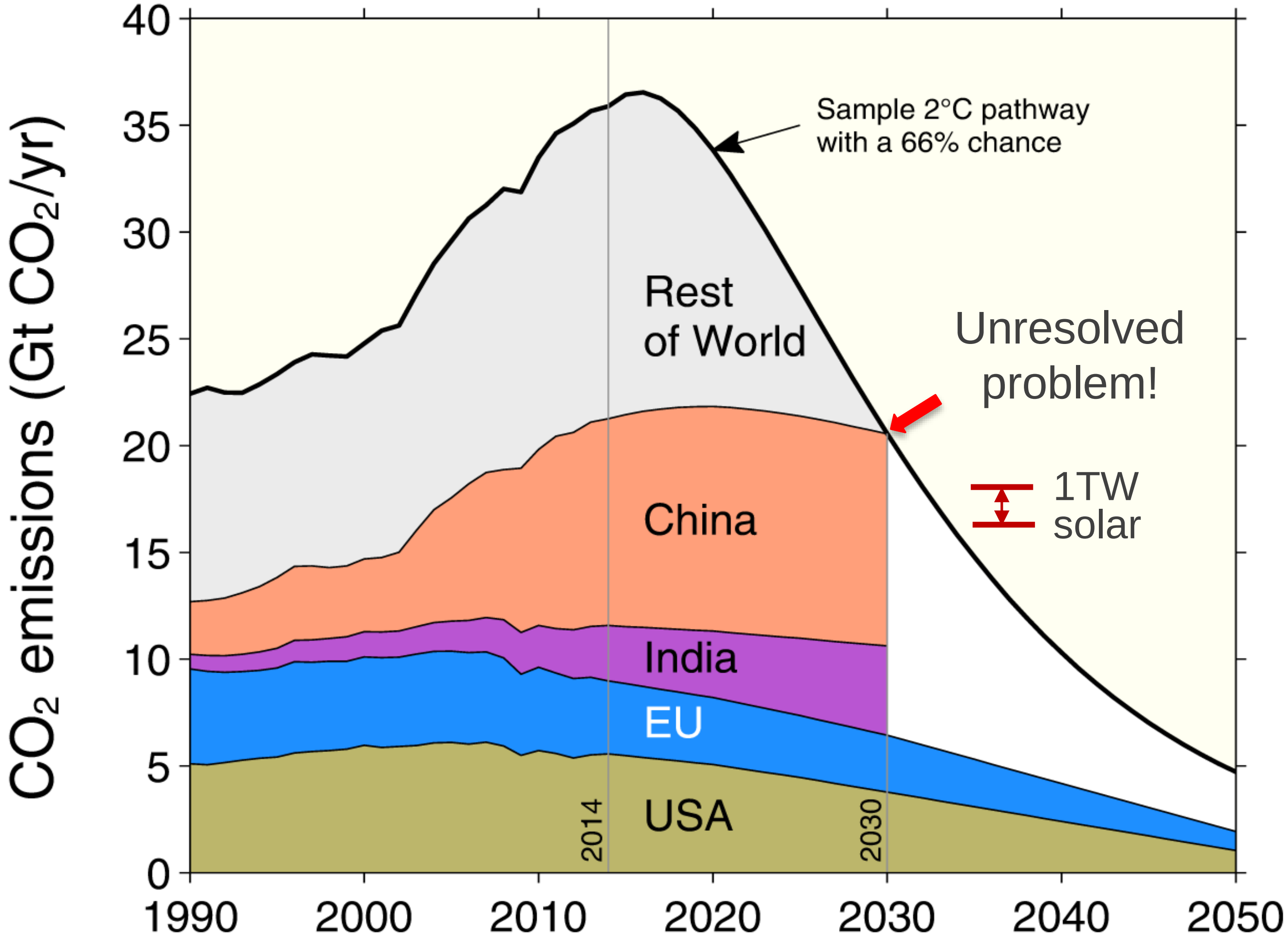
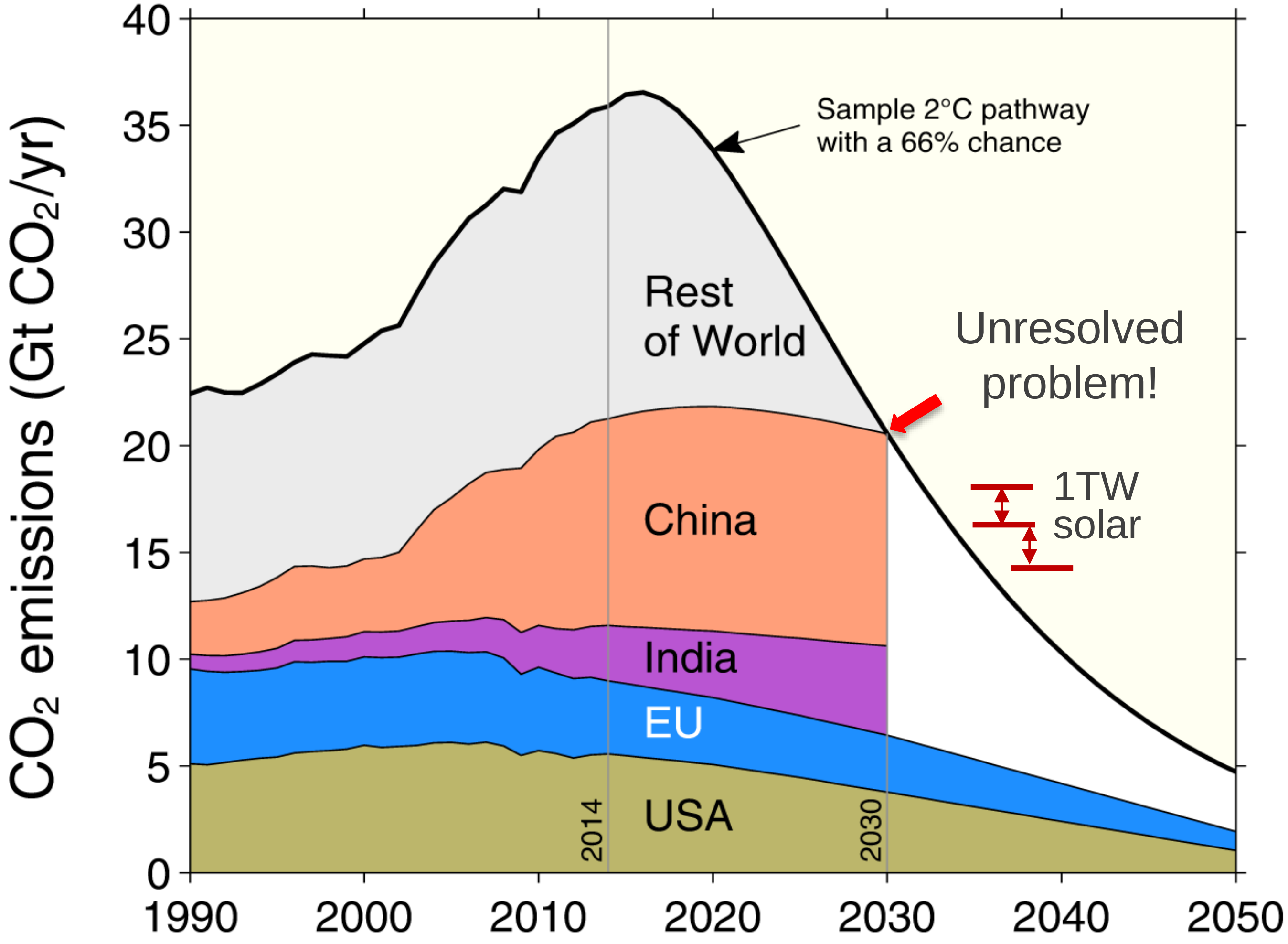
2ºC trajectory



2°C trajectory



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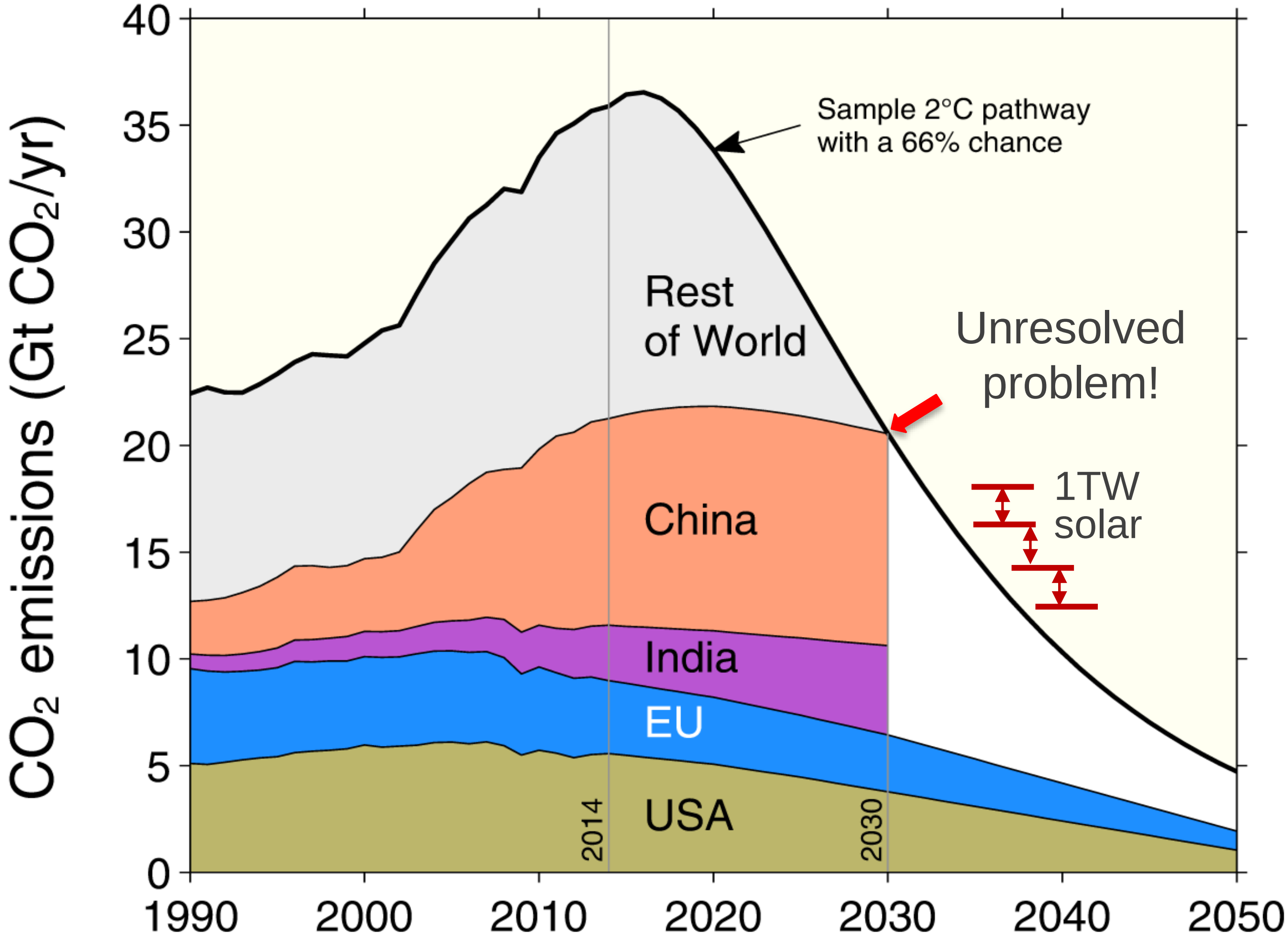
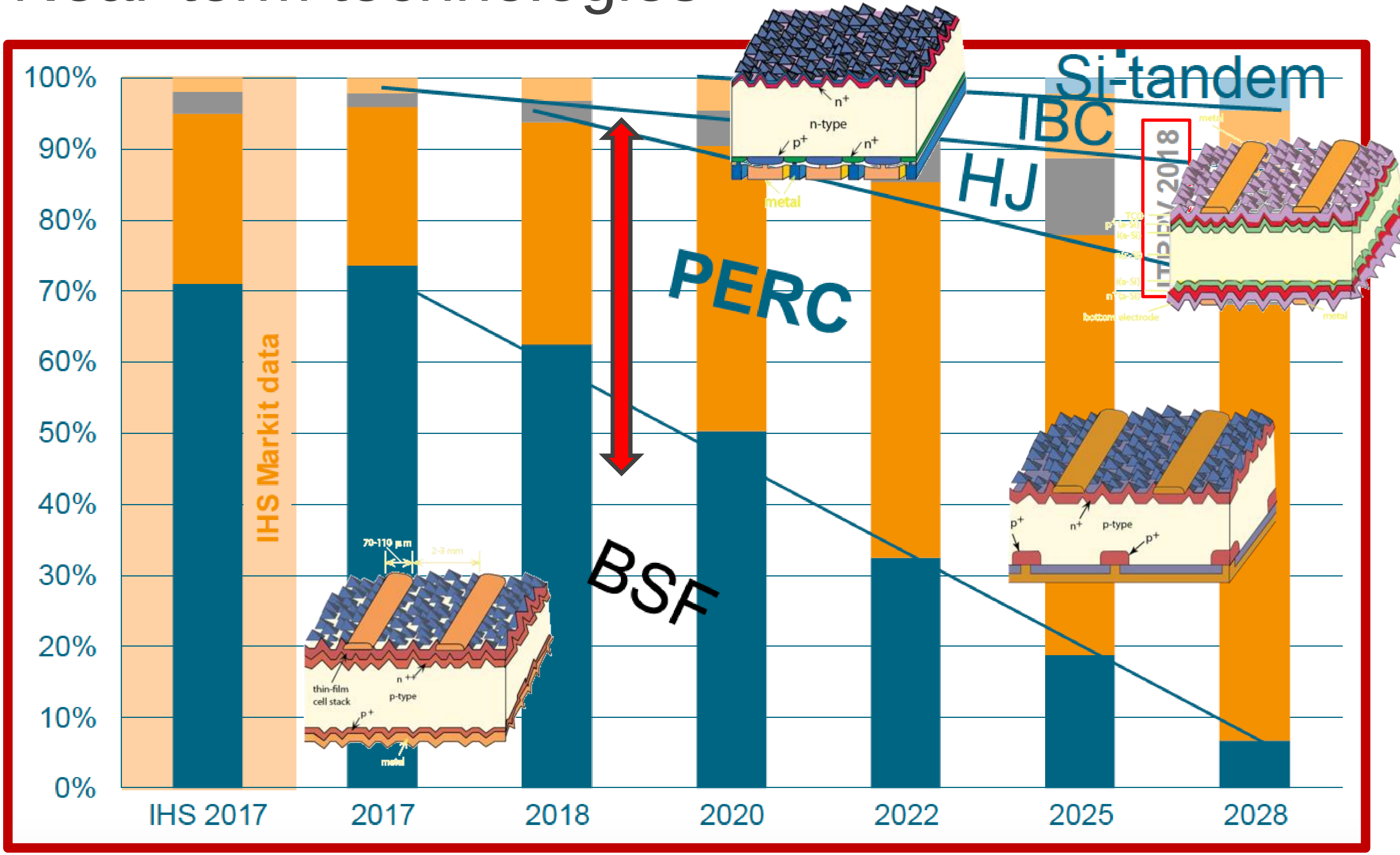


Near-term technologies



ITRPV 2018

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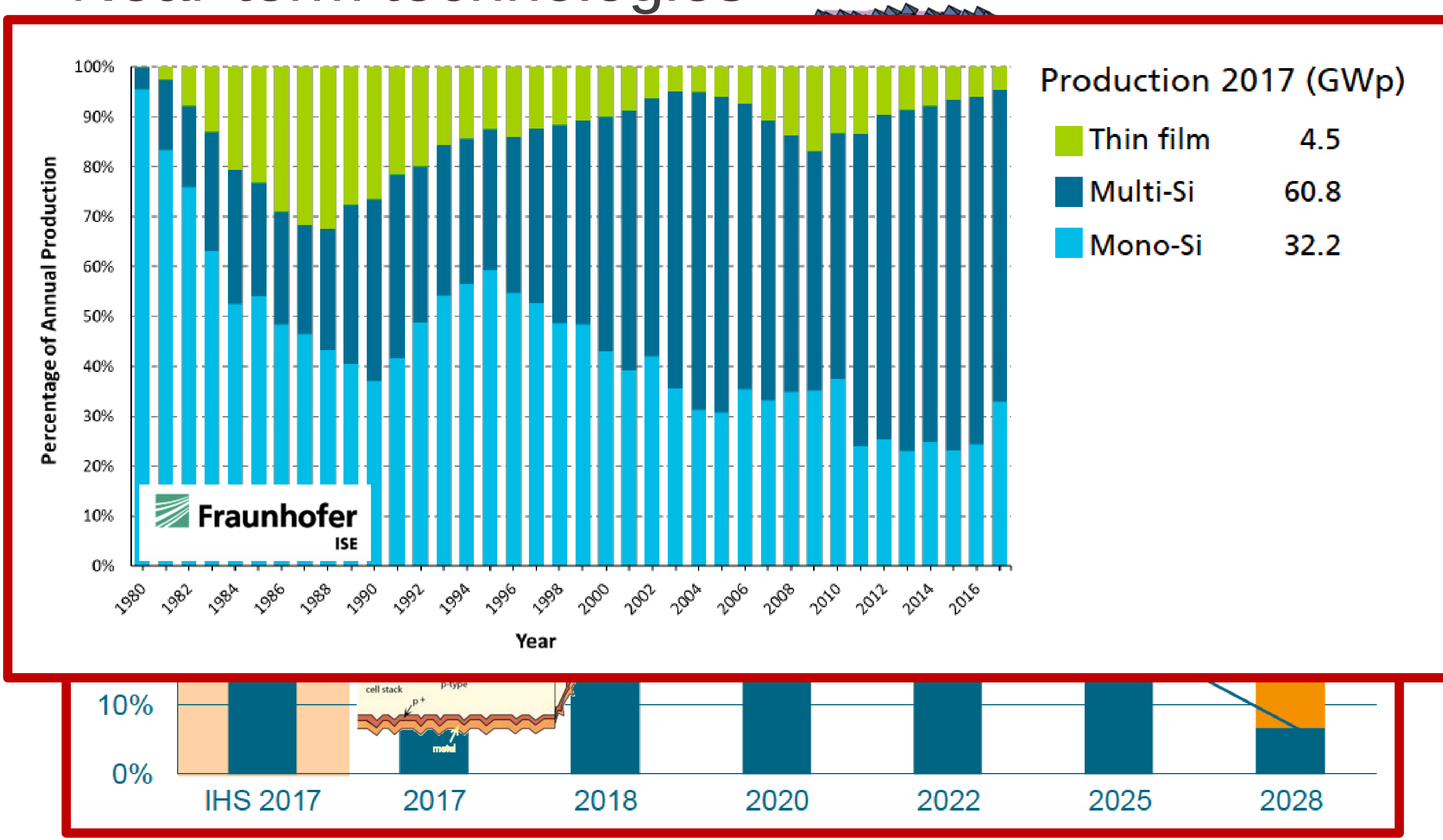

ITRPV 2018

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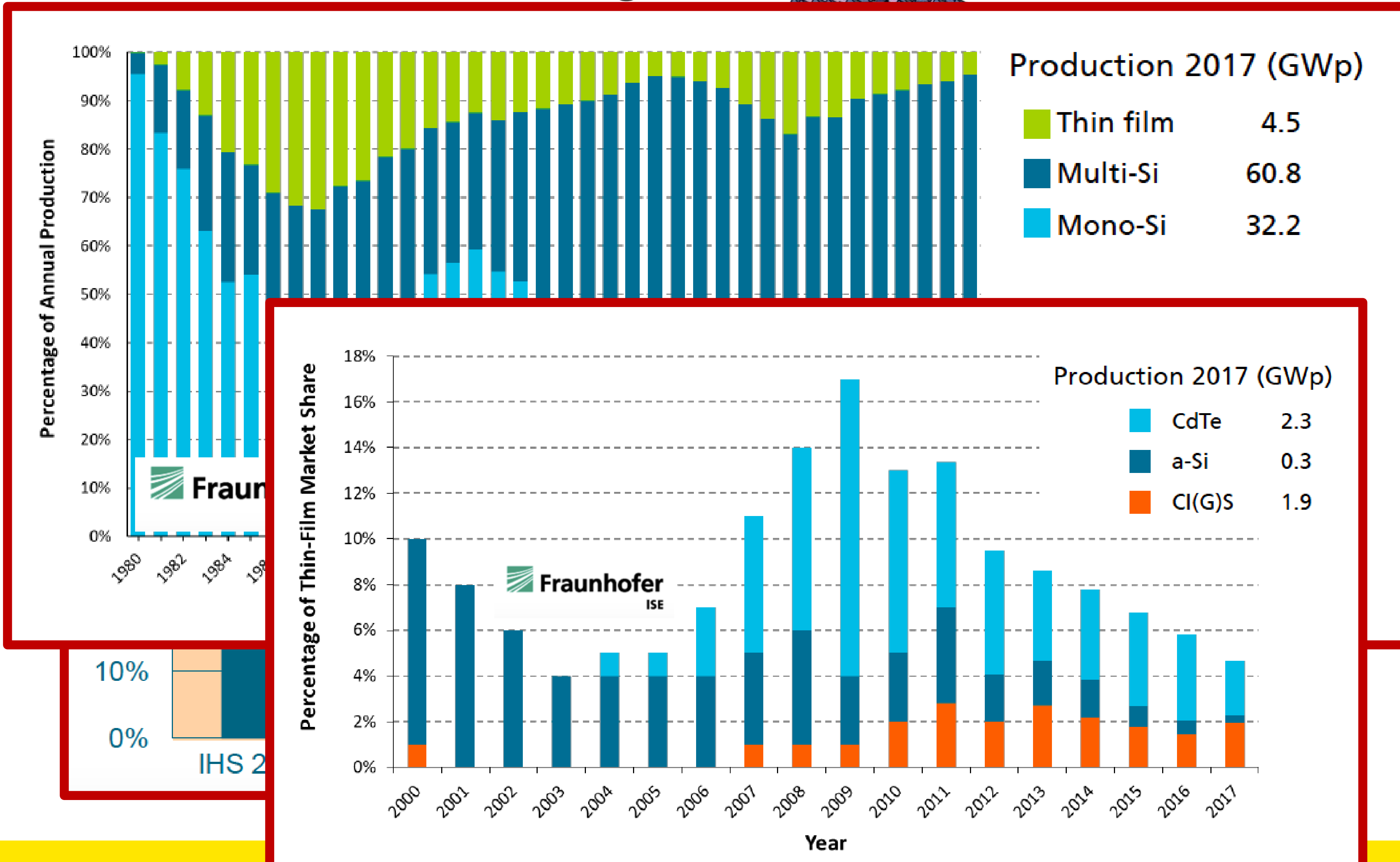
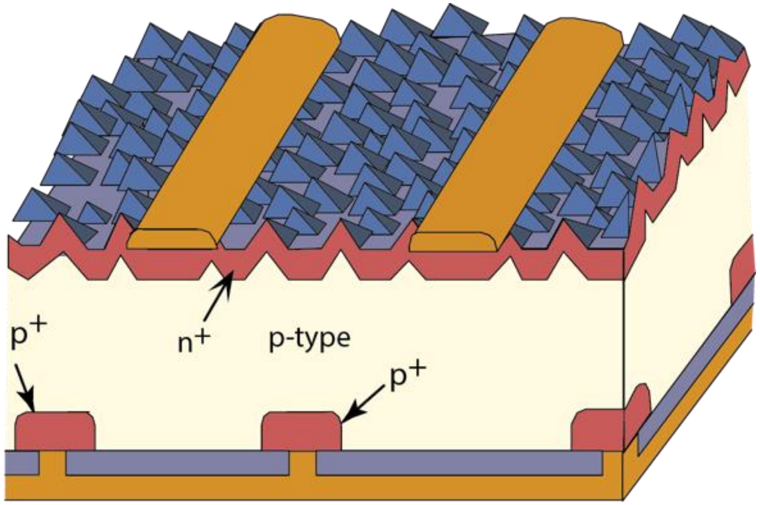
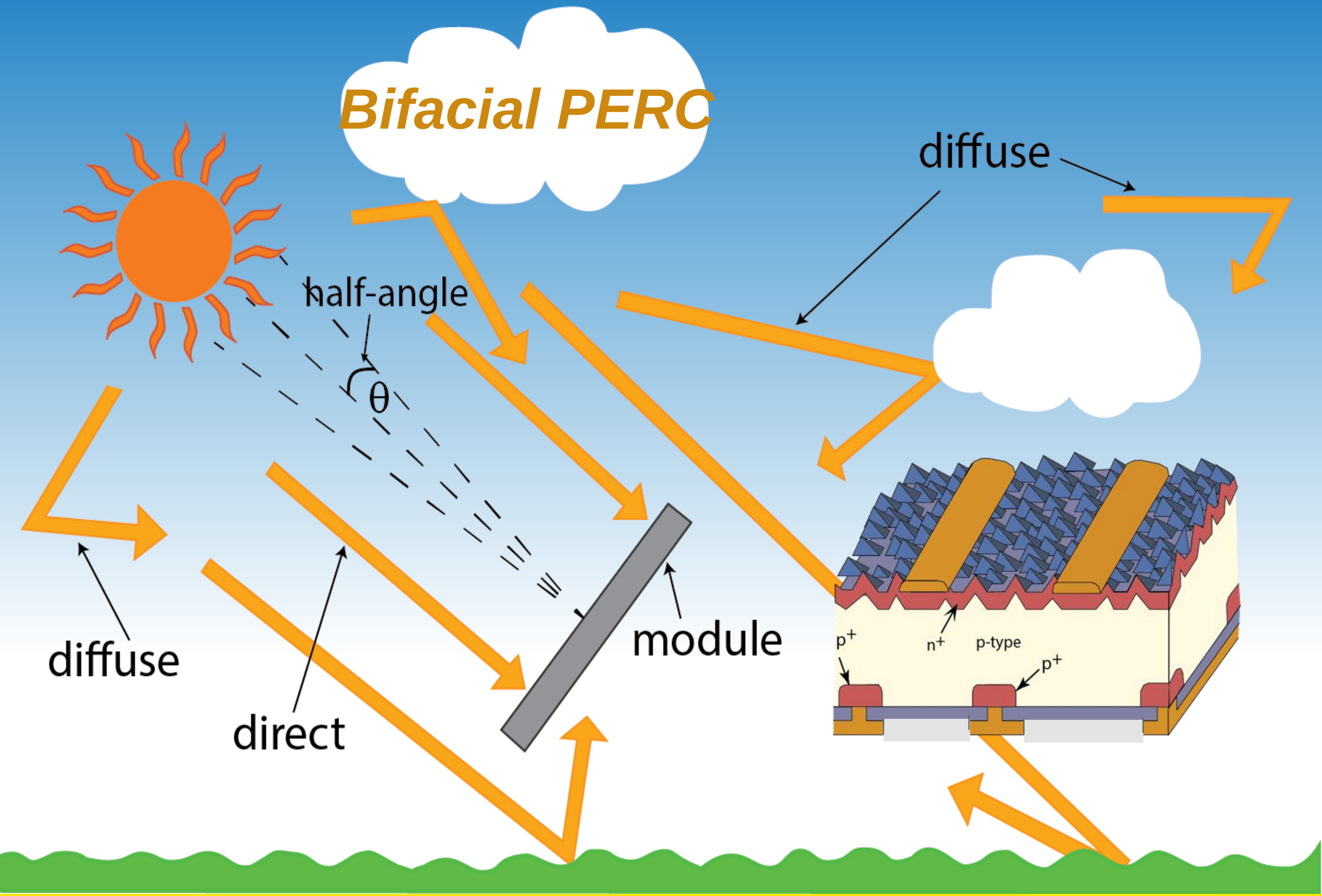


ITRPV 2018

What comes after PERC?

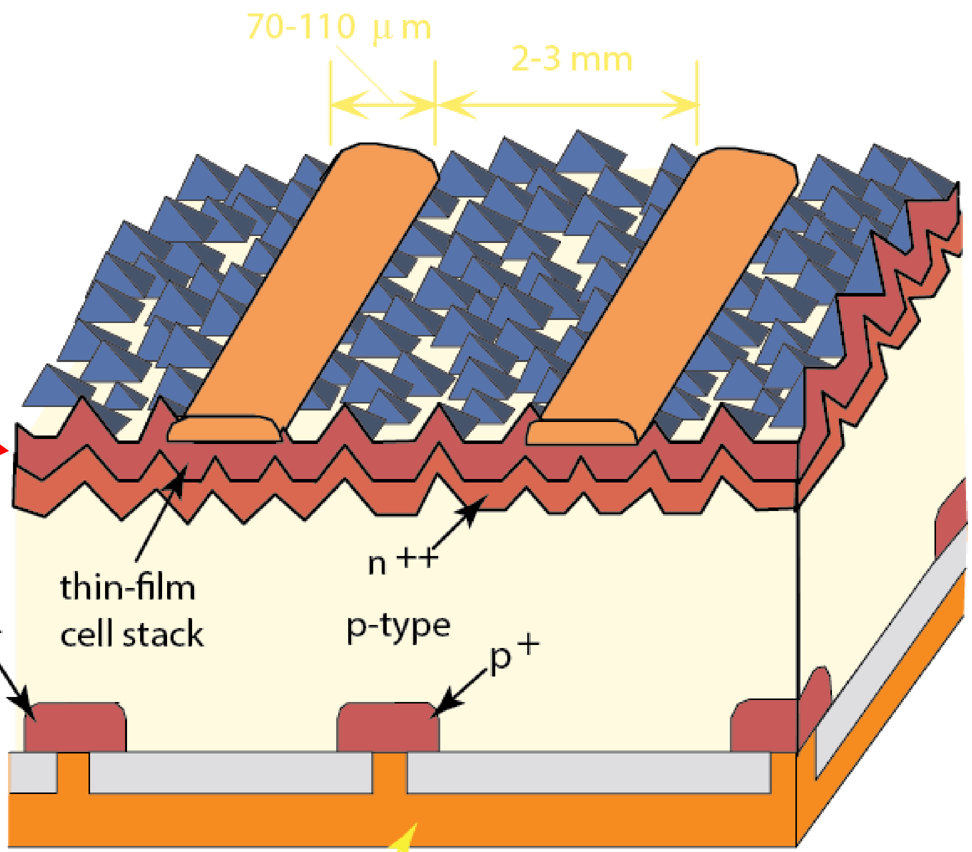


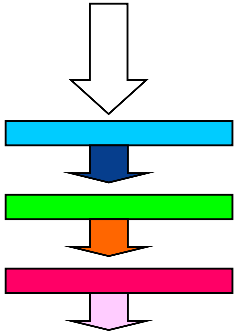
Bifacial PERC



What comes next?

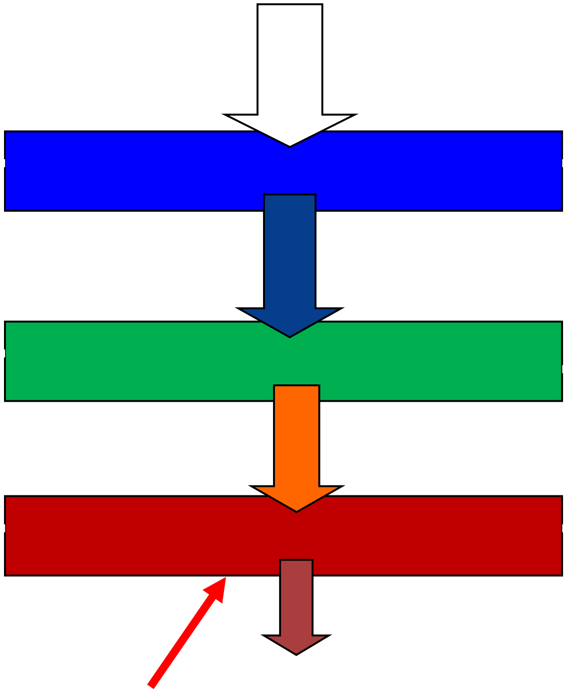
more sophisticated "active" AR coat?



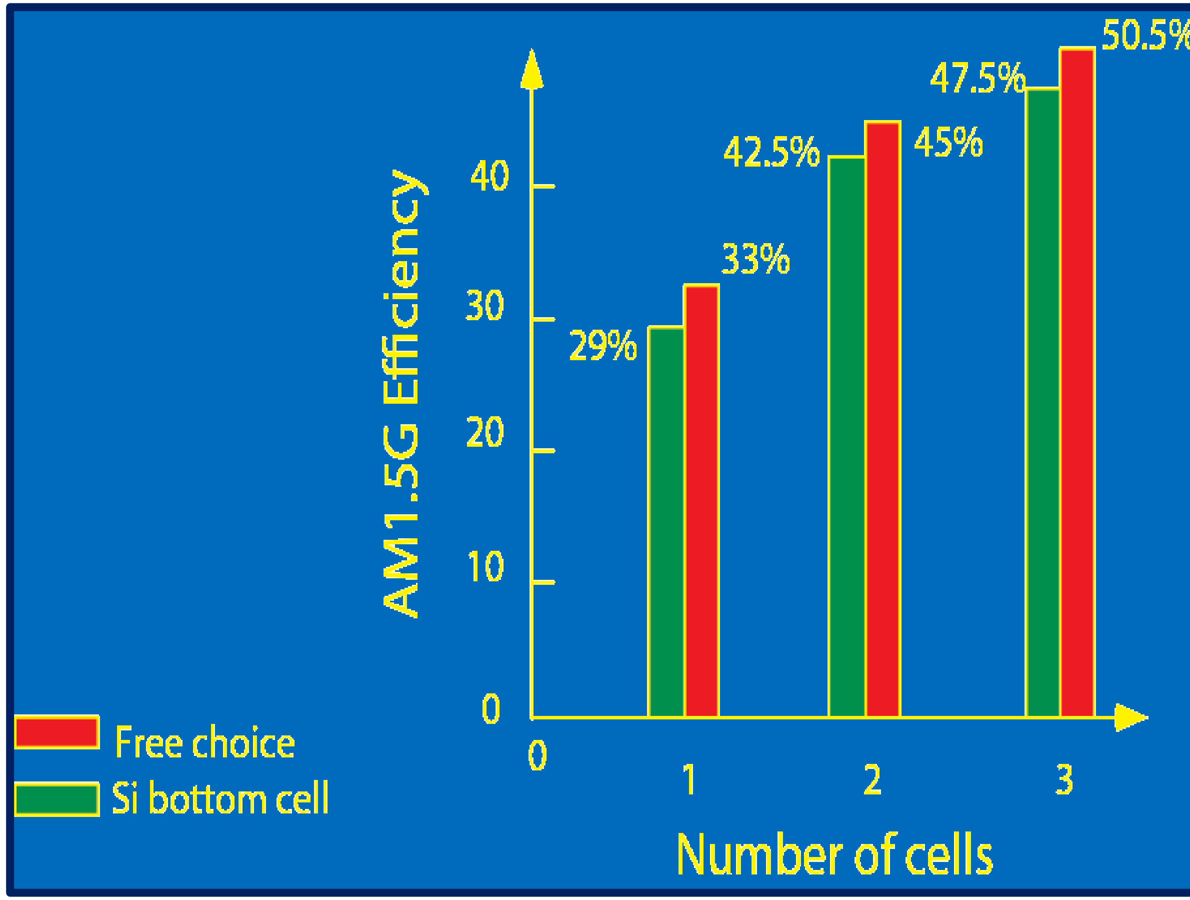


Supercharged PERC!

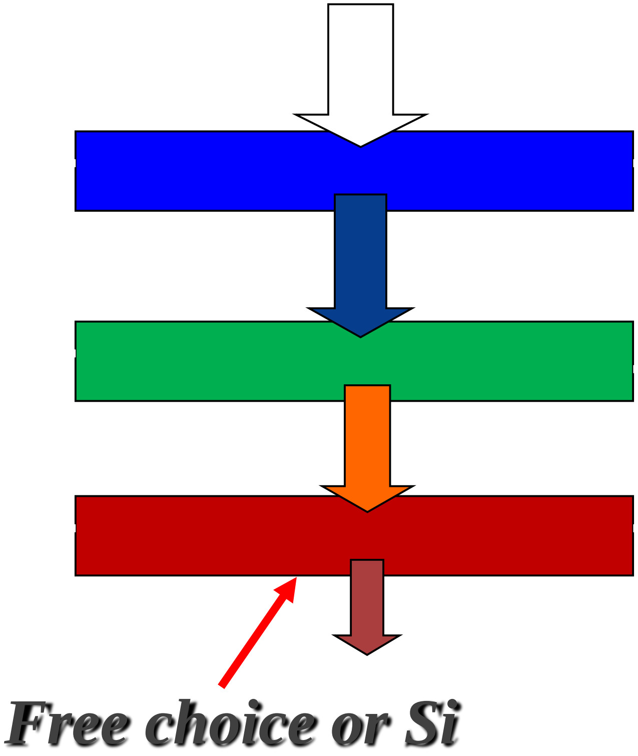
What comes after PERC?

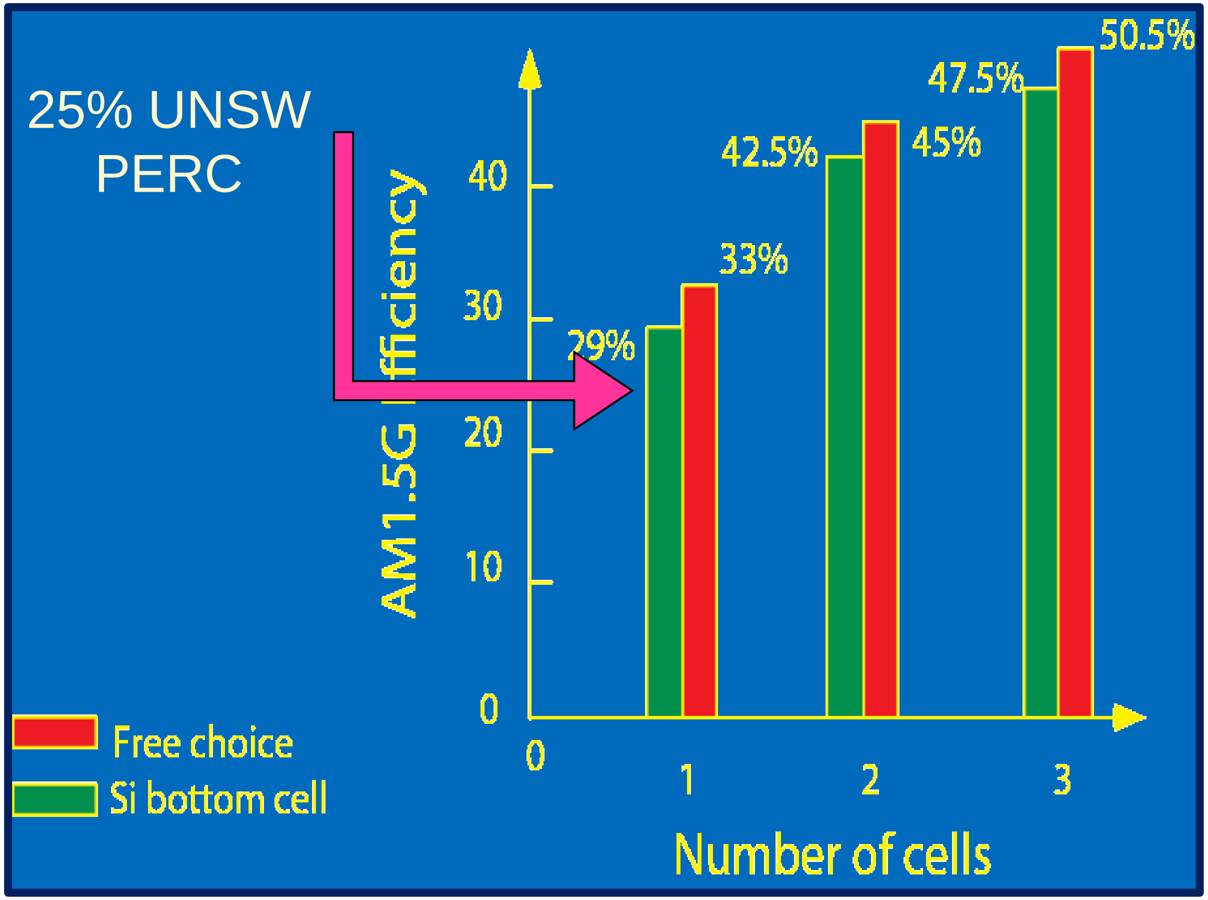


Free choice or Si



Next 10 years: What comes after PERC?





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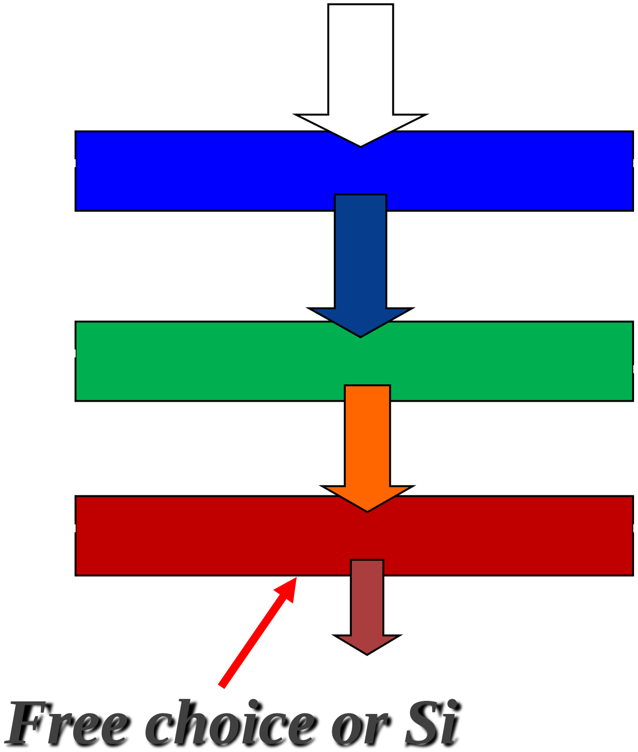

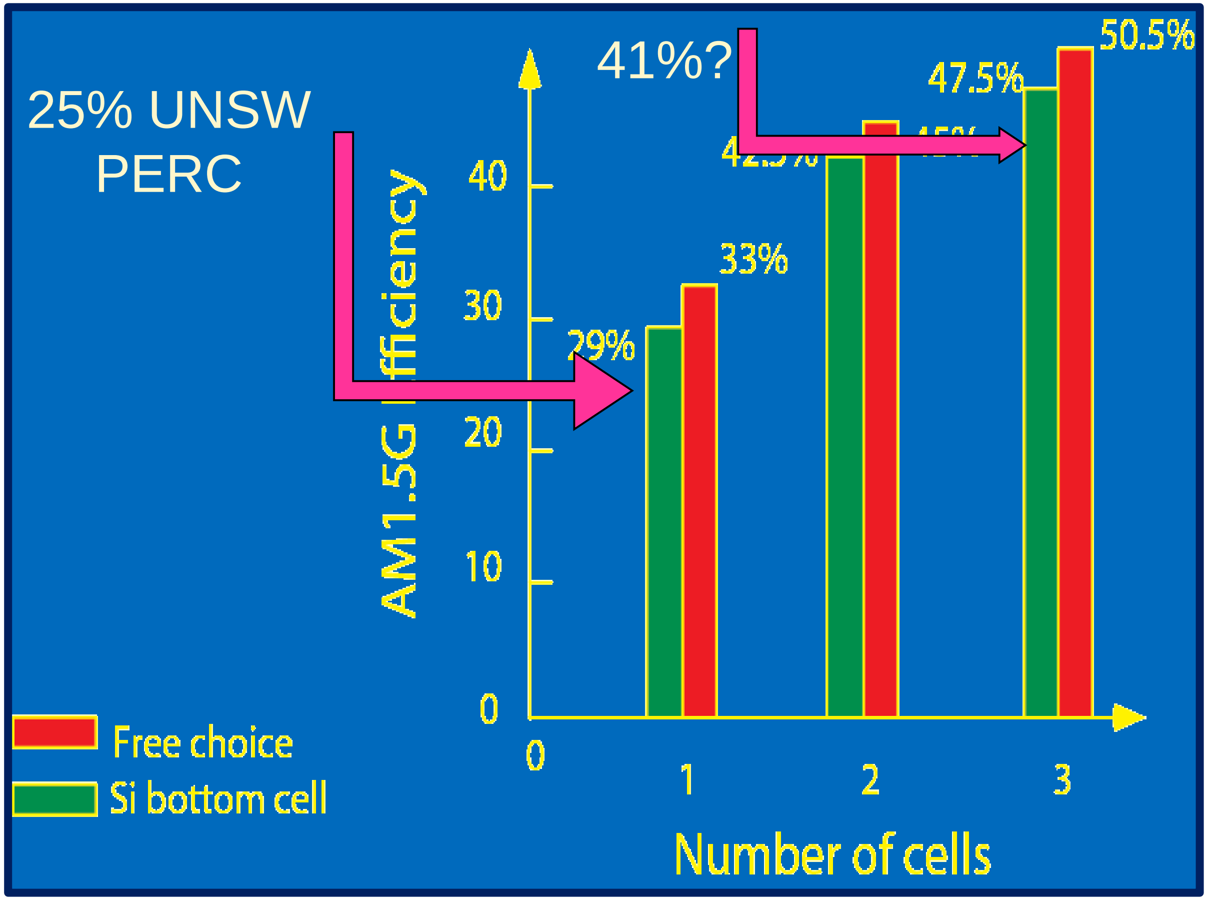

What comes after PERC?

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DOI: 10.1002/pip.3040

ACCELERATED PUBLICATION

WILEY PROGRESS IN PHOTOVOLTAICS

Check for updates

Solar cell efficiency tables (version 53)

Martin A. Green[1] | Yosh…
Jochen Hohl-Ebinger[5] | A…

TABLE 3
25°C (IEC

Classification	Efficiency (%)
III-V multijunctions	
5 Junction cell (bonded) (2.17/1.68/1.40/1.06/0.73 eV)	38.8 ± 1.2
InGaP/GaAs/InGaAs	37.9 ± 1.2
GaInP/GaAs (monolithic)	32.8 ± 1.4
Multijunctions with c-Si	
GaInP/GaAs/Si (mech. stack)	35.9 ± 0.5[c]
GaInP/GaAs/Si (wafer bonded)	33.3 ± 1.2[c]
GaAsP/Si (monolithic)	20.1 ± 1.3
GaAs/Si (mech. stack)	32.8 ± 0.5[c]
Perovskite/Si (monolithic)	25.2 ± 0.7[f]
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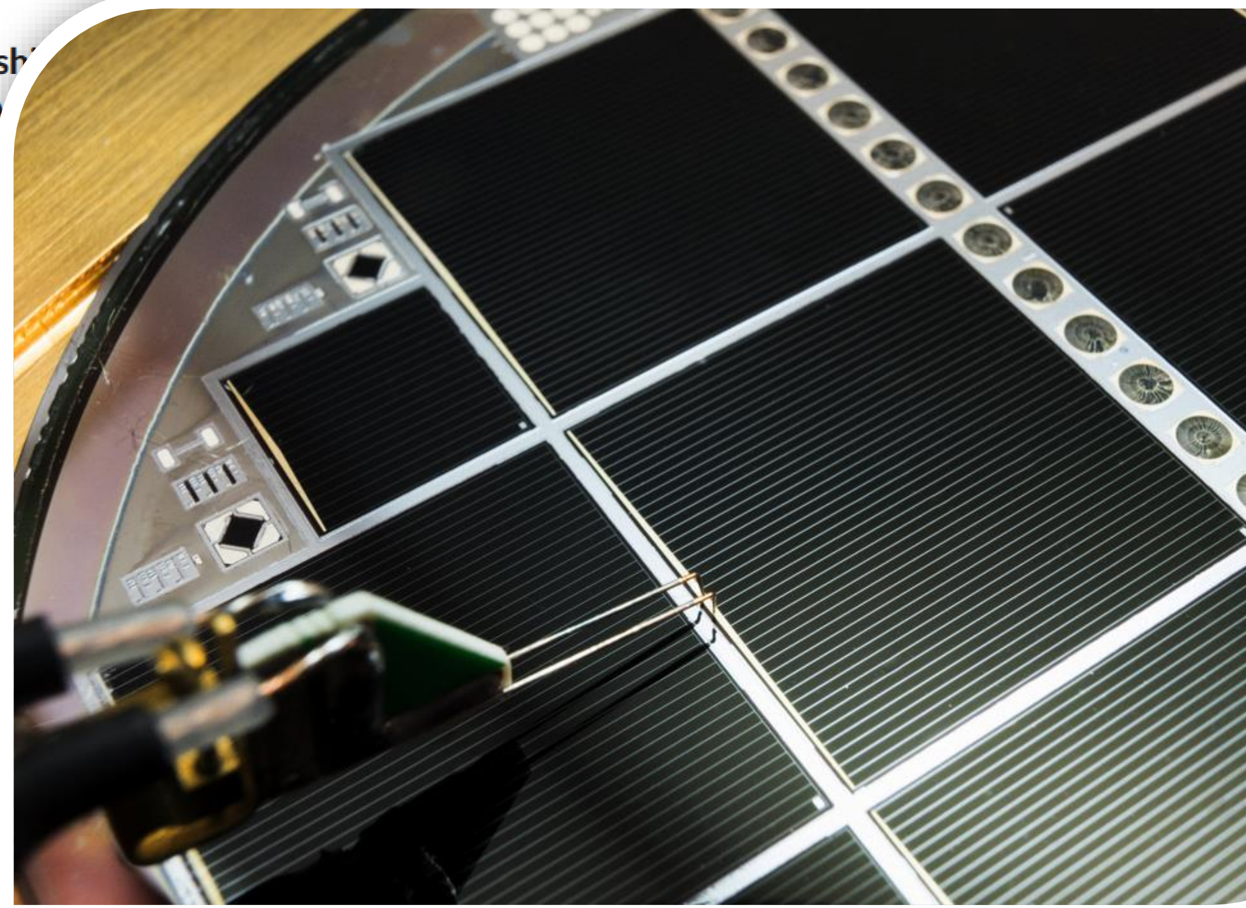
GaInP/GaInAs/Ge; Si (spectral split minimodule)	34.5 ±2.0



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GaInP/GaAs/Si (wafe	
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GaAs/Si (mec	32.8 ± 0.5[c]
Perovskite/Si (n hic)	25.2 ± 0.7[f]
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GaInP/GaInAs/Ge; Si (spectral split minimodule)	34.5 ±2.0

Expensive $$$$

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Ga scarce; As toxic

Expensive $$$$

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GaInP/GaAs (monolithic)	32.8 ± 1.4	1.000 (ap)
Multijunctions with c-Si		
GaInP/GaAs/Si (mech. stack)	35.9 ± 0.5[c]	1.002 (da)
GaInP/GaAs/Si (wafer bonded)	33.3 ± 1.2[c]	3.984 (ap)
GaAsP/Si (monolithic)	20.1 ± 1.3	3.940 (ap)
GaAs/Si (mech. stack)	32.8 ± 0.5[c]	1.003 (da)
Perovskite/Si (monolithic)	25.2 ± 0.7[f]	1.419 (da)
Perovskite/Si (monolithic)	27.3 ± 0.8[f]	1.088 (da)
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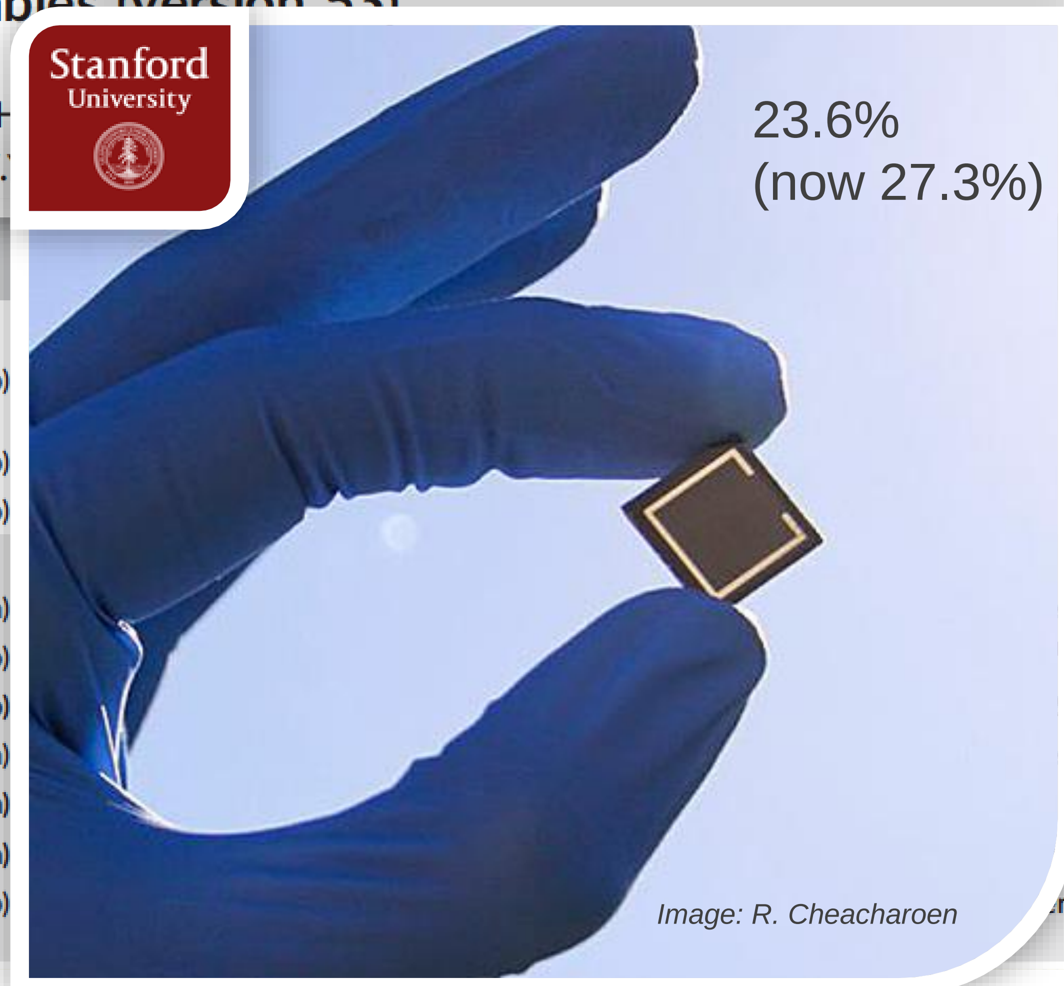

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Stanford University

Image: R. Cheacharoen

Stability issues?

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Pb toxic

Stability is ... es?

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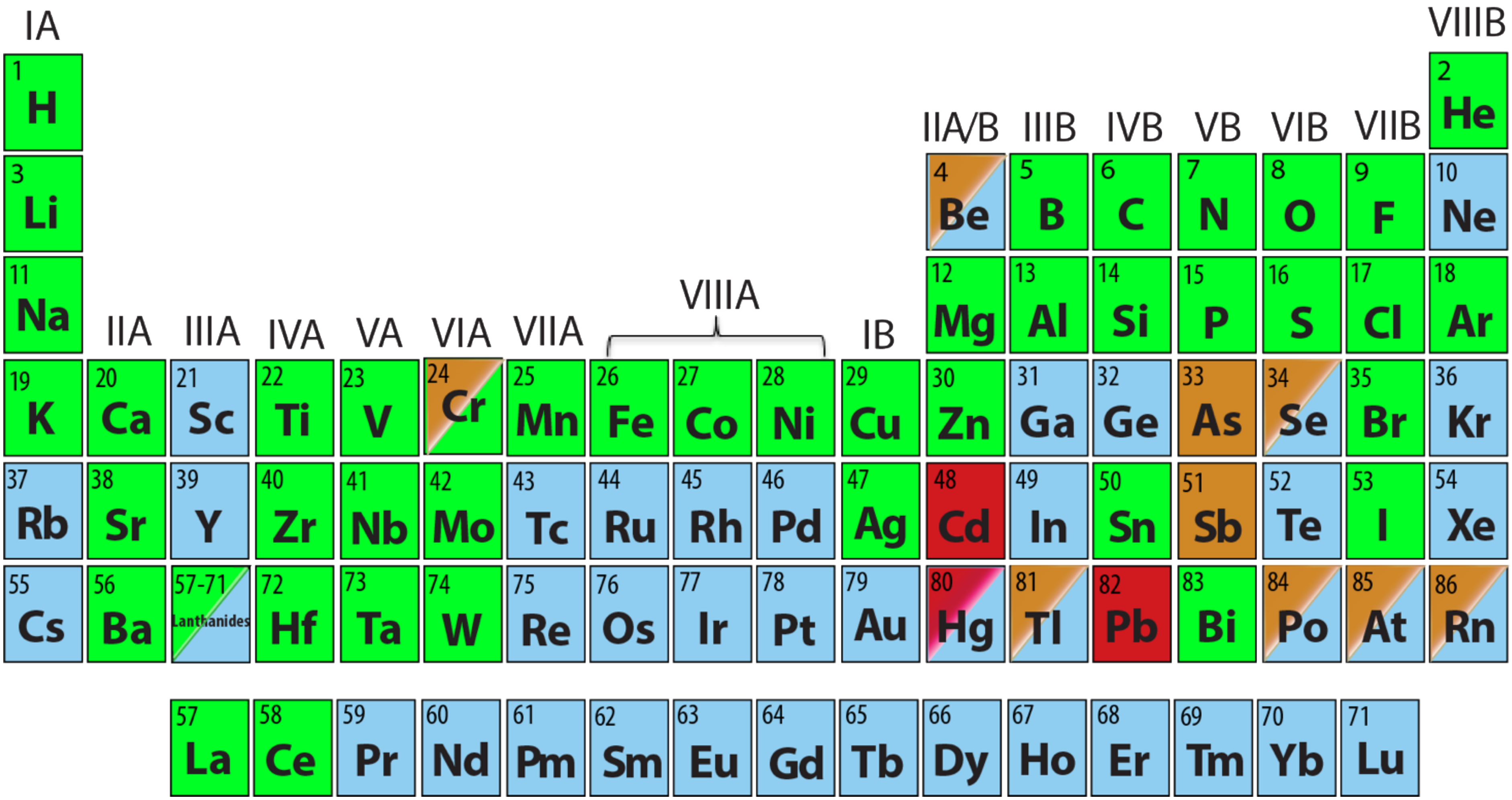

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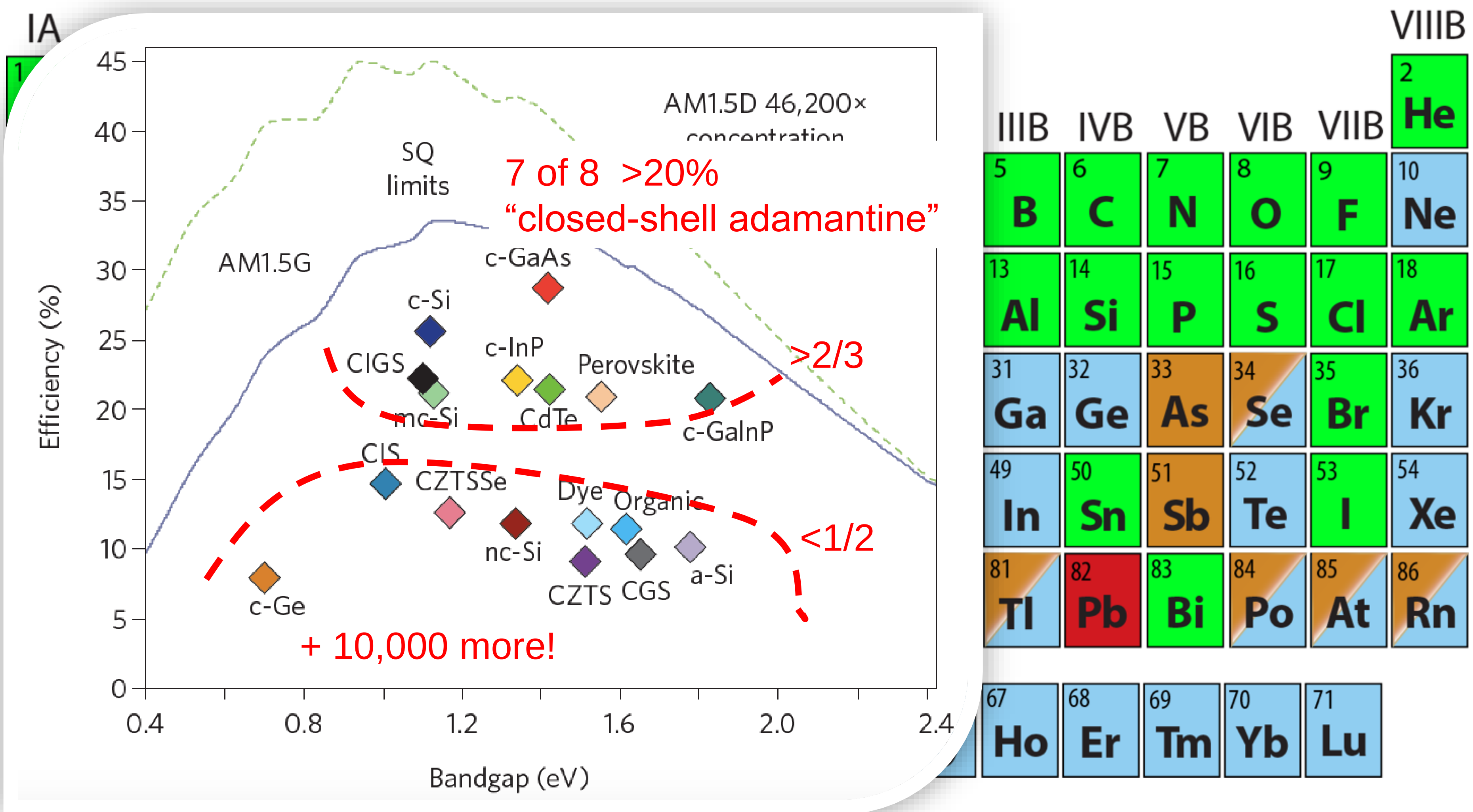

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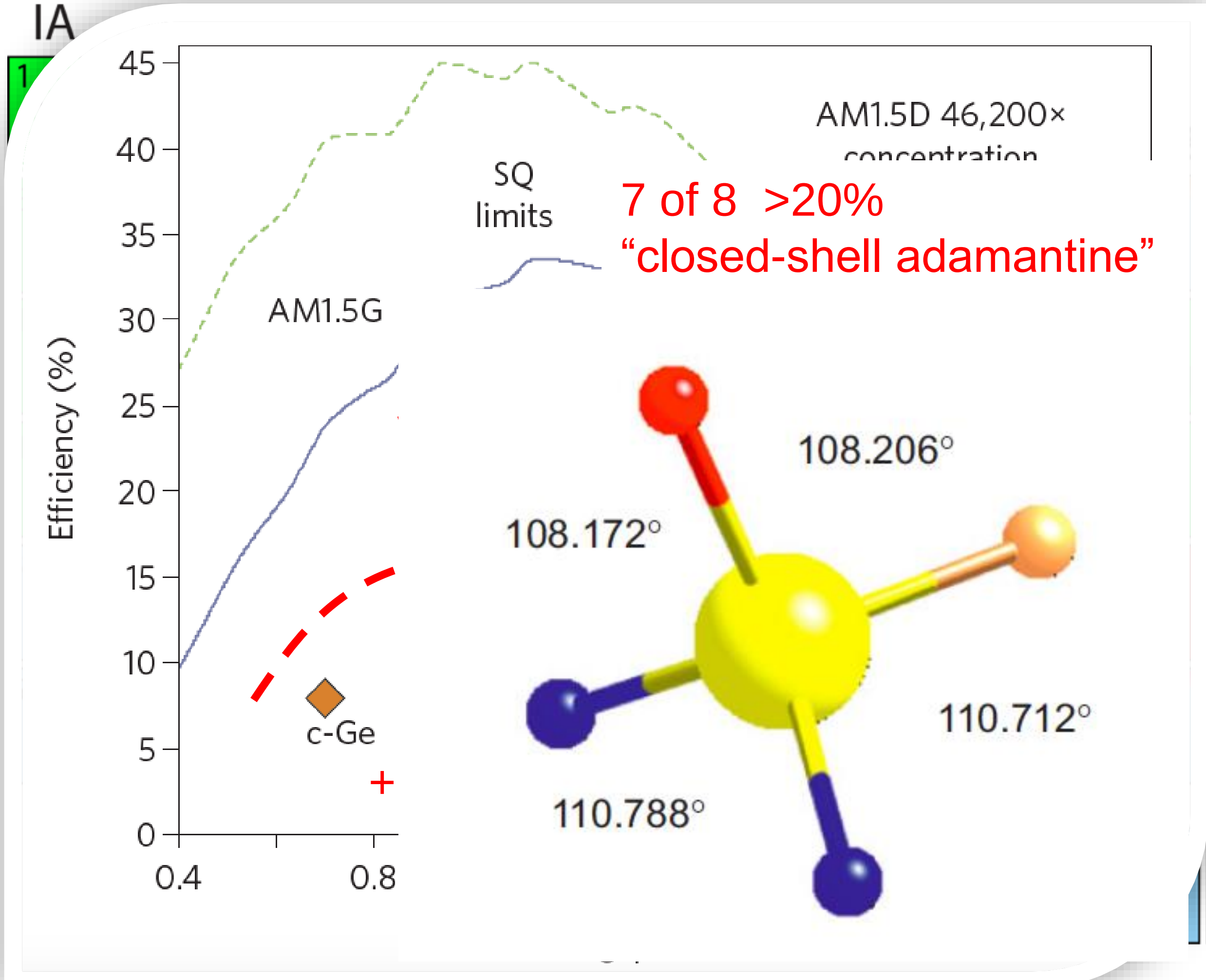

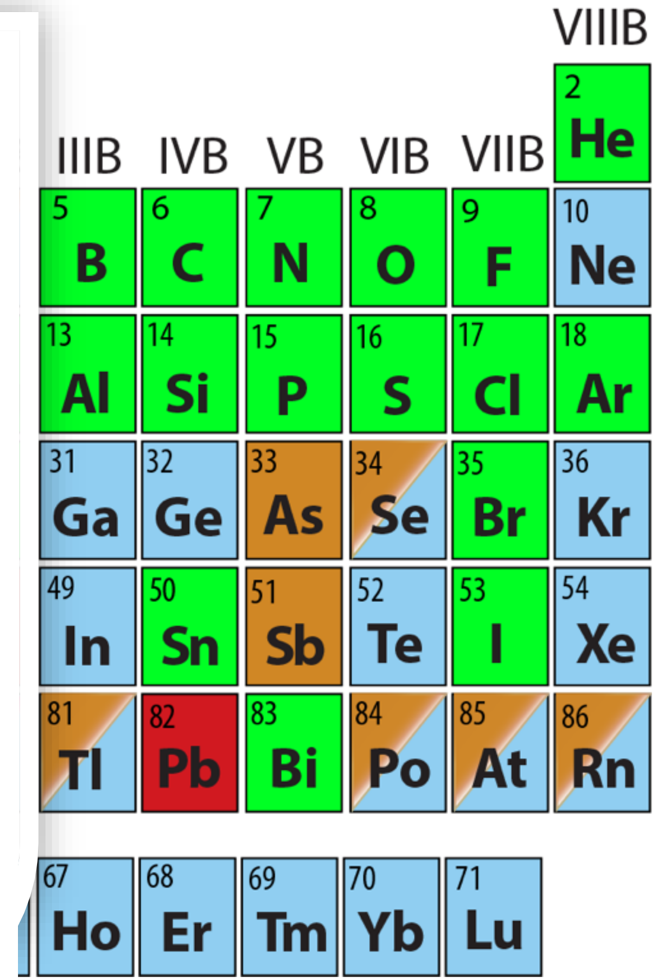

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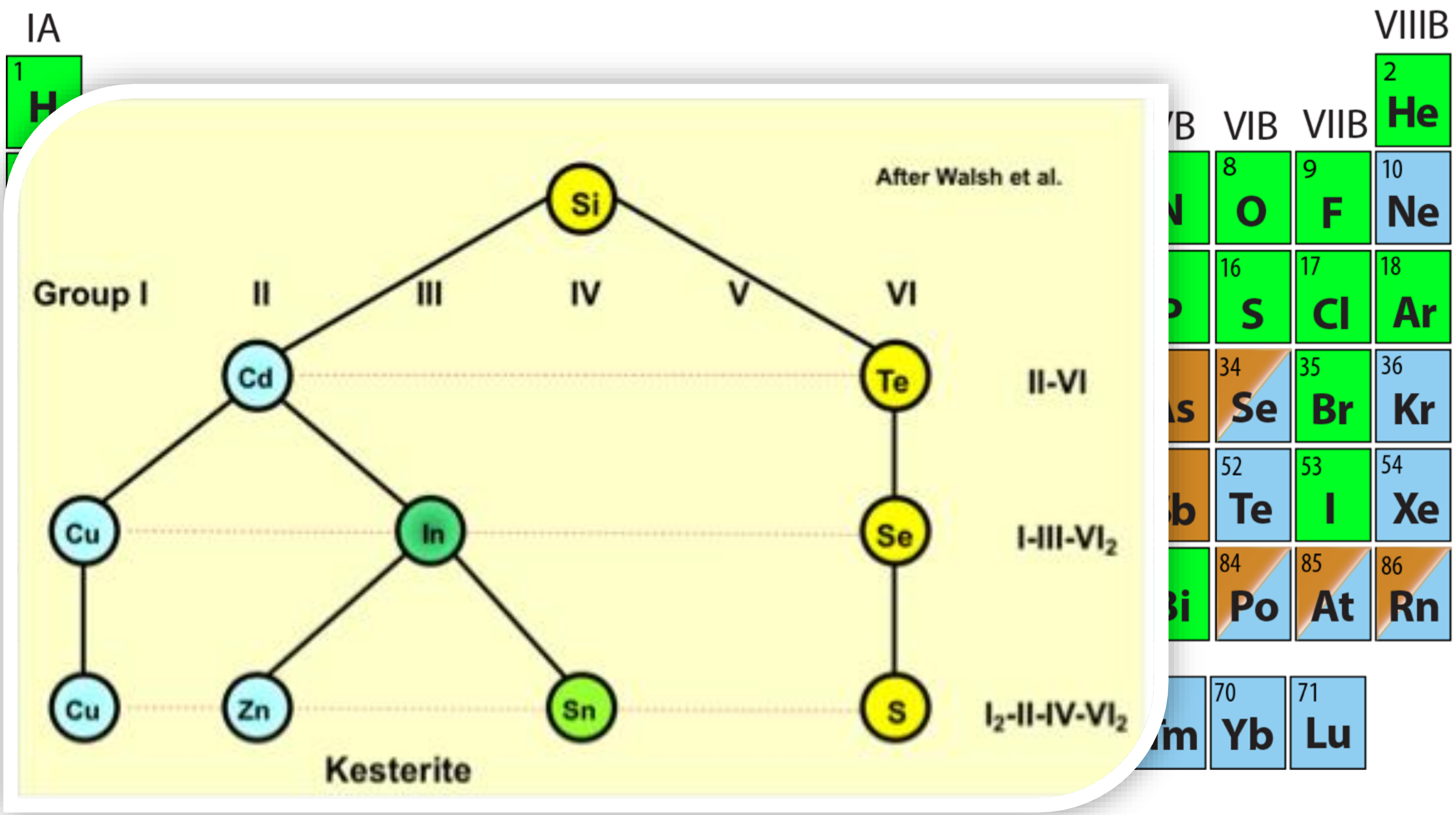

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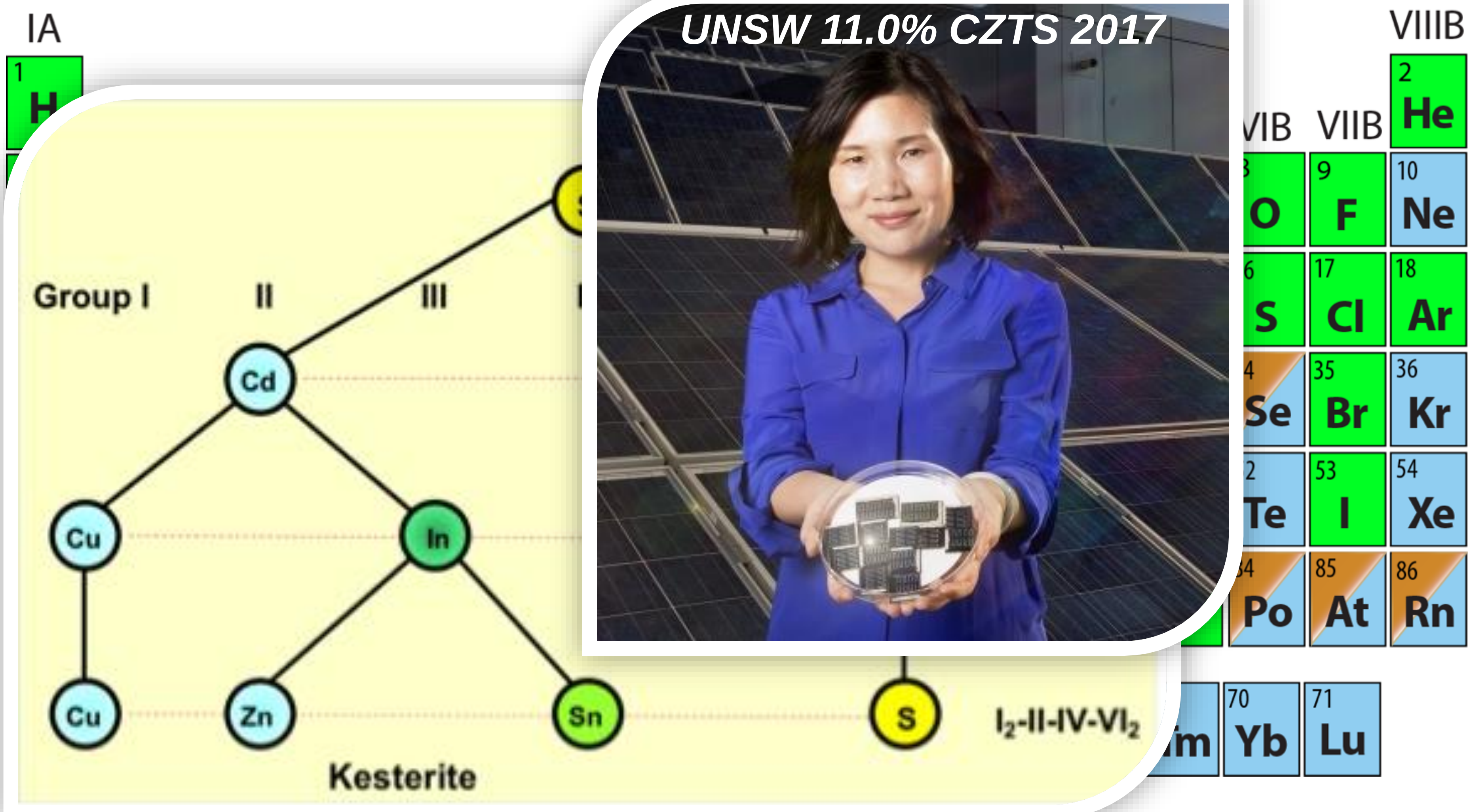

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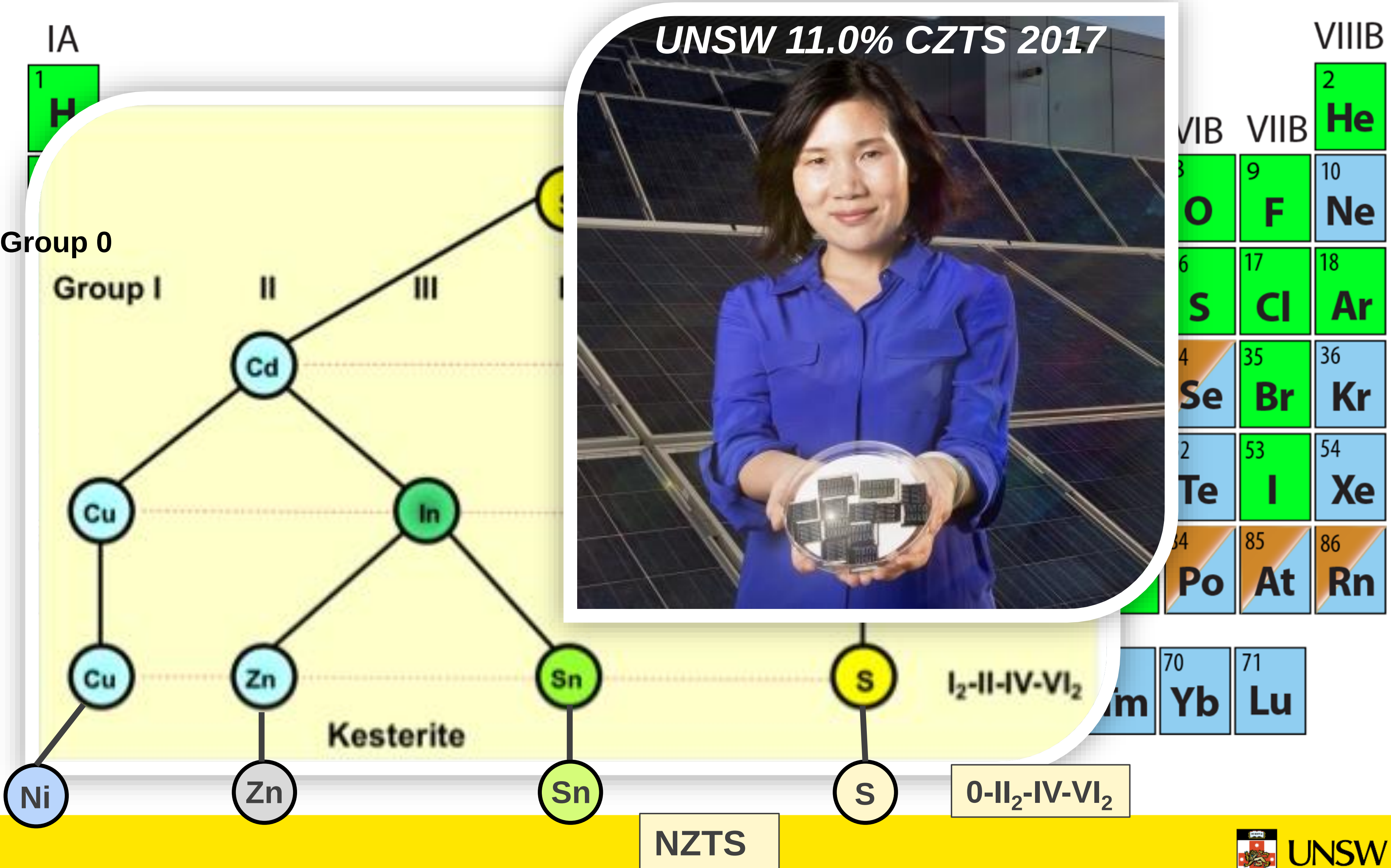

What comes after PERC?

le 1: *Families of Potential Closed-Shell Adamantine Semiconductors*

		BINARY	TERNARY	QUATERNARY	QUINTERNARY
	I-VII	(I$_2$-VII$_2$)	0-II-VII$_2$		**Halides**
		(I$_3$-VII$_3$)*	(0$_2$-III-VII$_3$)	(0-I-II-VII$_3$)	
		(I$_4$-VII$_4$)	0$_3$-IV-VII$_4$	0-I$_2$-II-VII$_4$	
				0$_2$-I-III-VII$_4$	
	II-VI	(II$_2$-VI$_2$)	0-IV-VI$_2$		**Chalcogenides**
			I-III-VI$_2$		
		(II$_3$-VI$_3$)*	(0-III$_2$-VI$_3$)	(0-I-V-VI$_3$)	
IV			(I$_2$-IV-VI$_3$)	(0-II-IV-VI$_3$)	
				(I-II-III-VI$_3$)	
		(II$_4$-VI$_4$)	I$_3$-V-VI$_4$	0-II-III$_2$-VI$_4$	0-I-II-V-VI$_4$
				0-II$_2$-IV-VI$_4$	0-I-III-IV-VI$_4$
				I-II$_2$-III-VI$_4$	
				I$_2$-II-IV-VI$_4$	
	III-V	(III$_2$-V$_2$)	II-IV-V$_2$		**Pnictides**
		(III$_3$-V$_3$)*	(I-IV$_2$-V$_3$)	(II-III-IV-V$_3$)	
		(III$_4$-V$_4$)	0-IV$_3$-V$_4$	I-III-IV$_2$-V$_4$	
				II-III$_2$-IV-V$_4$	
	IV-IV	*Anions surrounded by different cation combinations			

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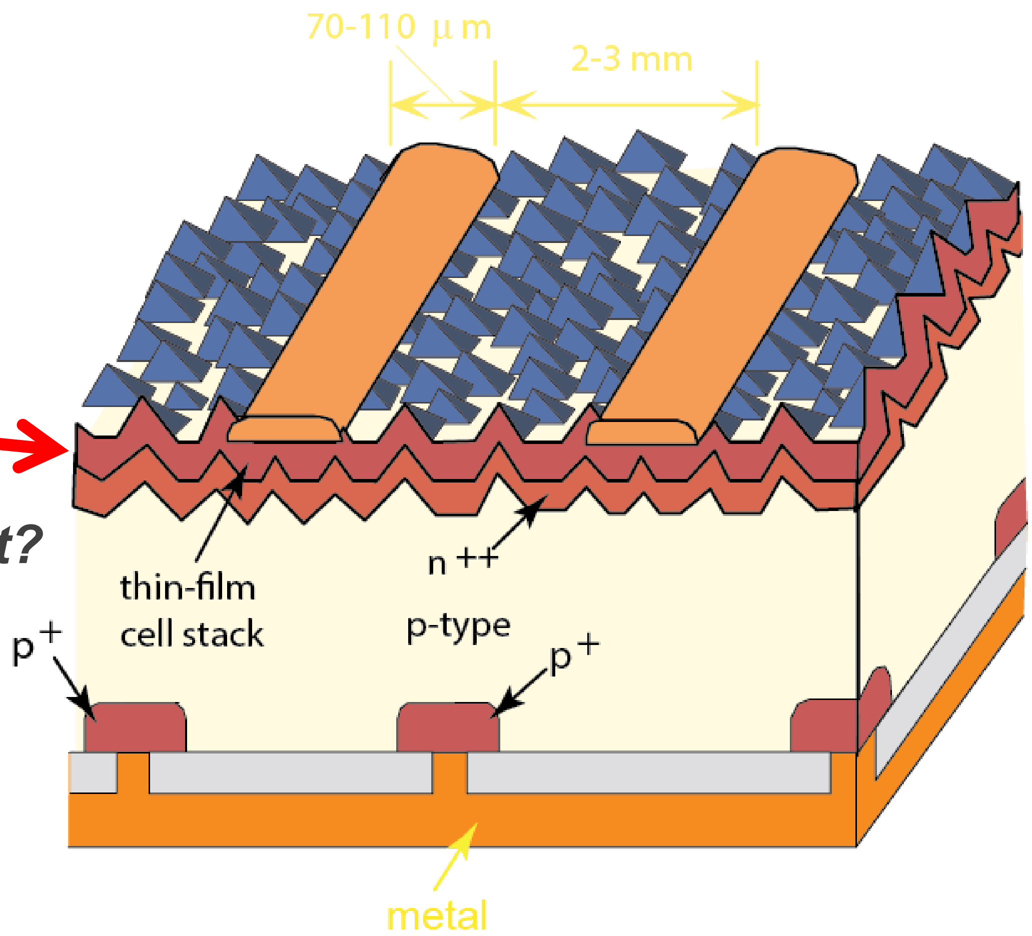
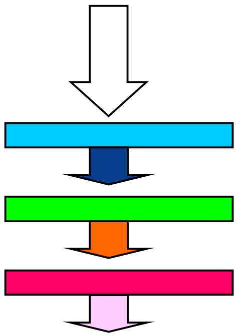
What comes after double-junction PERC?

more sophisticated "active" AR coat?





Triple-junction PERC! – middle cell nearly for free!

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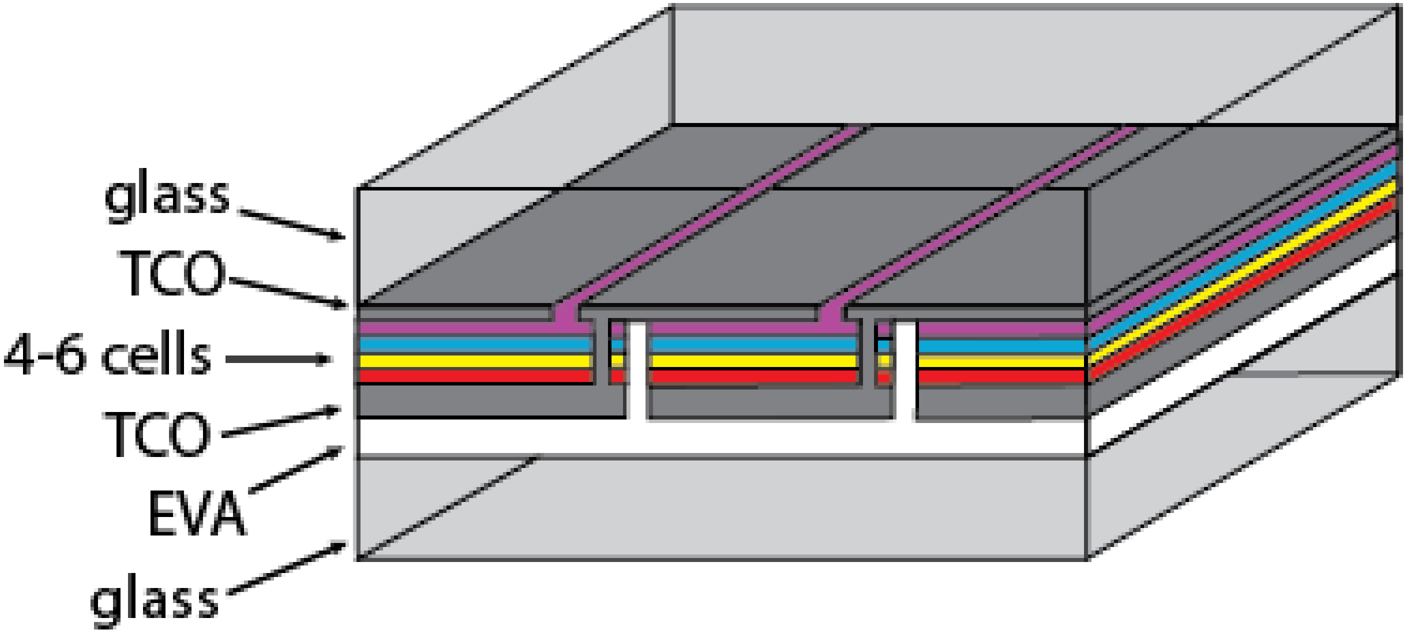
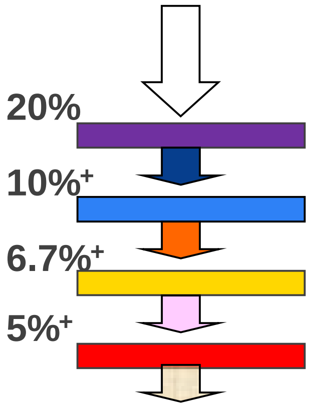
What comes after triple-junction PERC?





Quadruple-junction thin-film!

‘Current overview of PV technologies and PV technology visions for the future’

<u>5-10 years forward</u>:

Si continues to dominate;

PERC perfected (>25% in production)(H_2);

Multicrystalline or mono? n-type grows

Higher efficiency – tandem most realistic option;

What top cell material?

Polycrystalline chalcogenide?

<u>15-20 years forward</u>:

3-cell Si based tandems

Then 4[+] thin-film tandems

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