

Faculty of Engineering
School of Photovoltaic and Renewable Energy Engineering



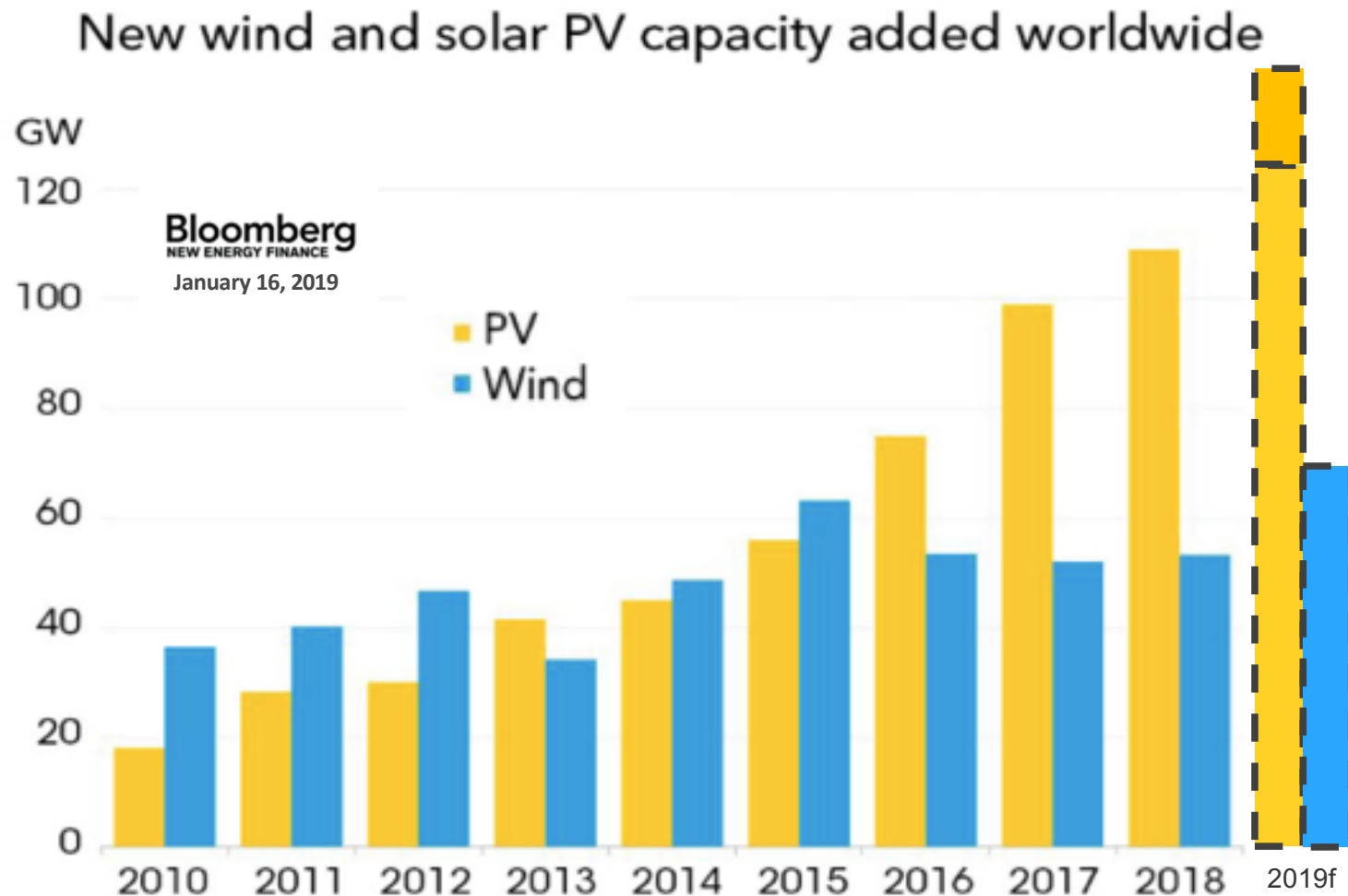
Solar Photovoltaics: Recent Progress & Future Potential

Martin A. Green
September, 2019



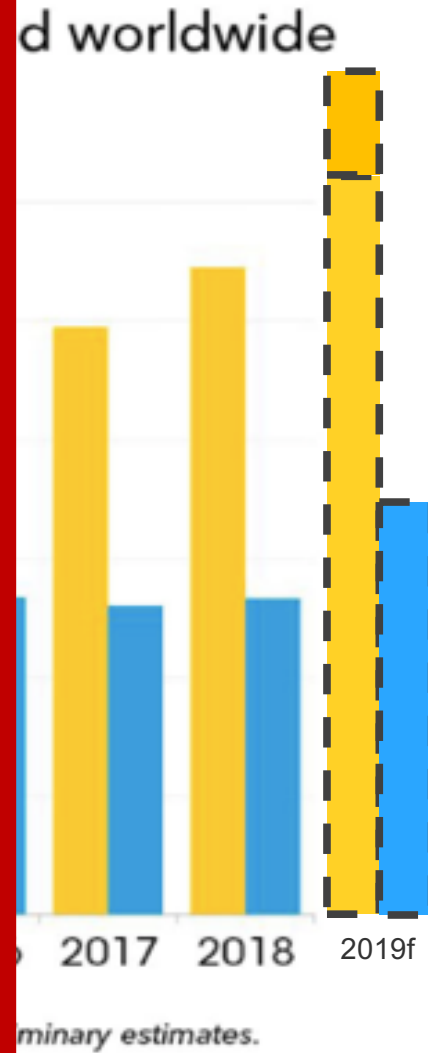
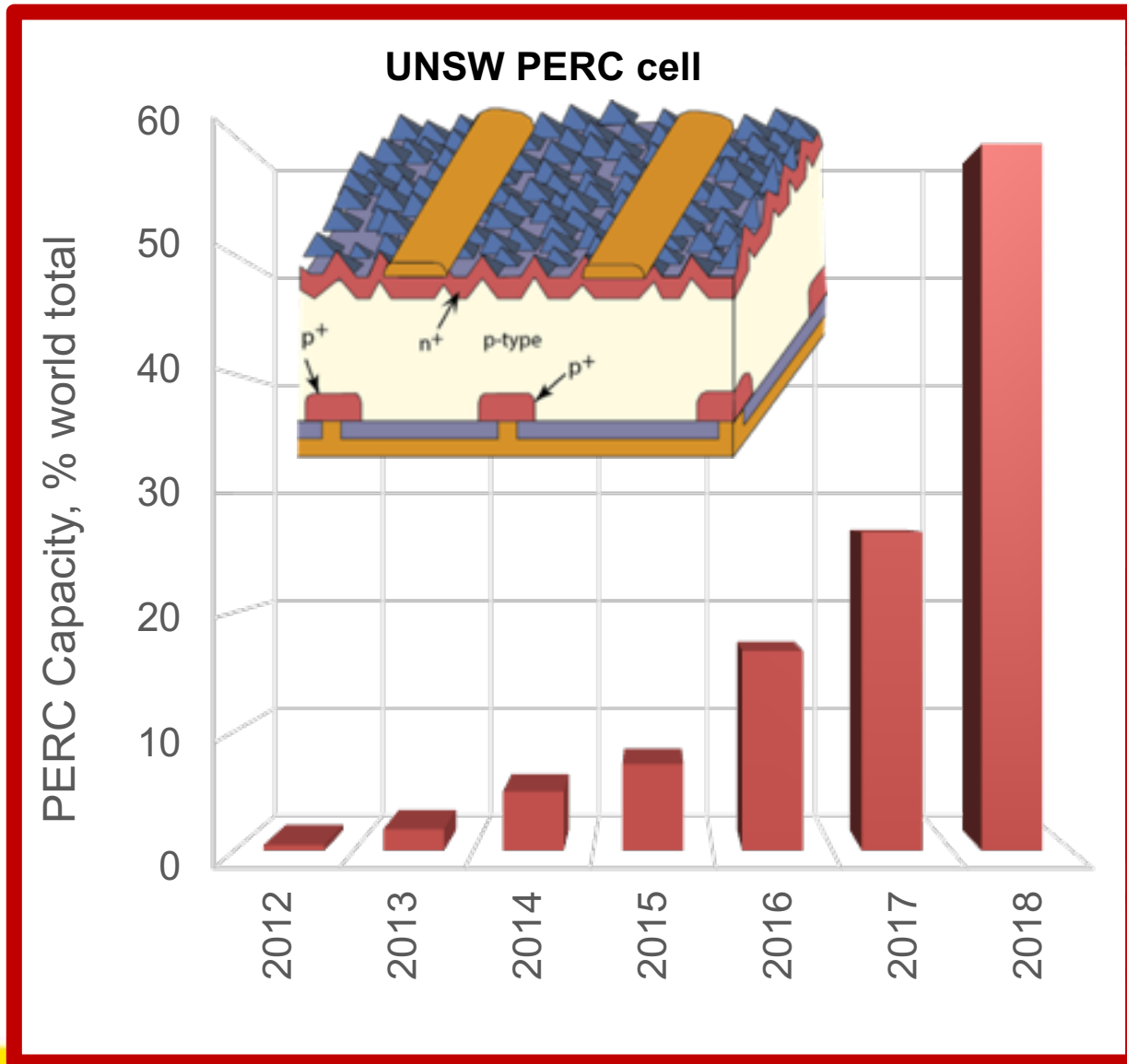
- 
1. Technology
 2. Markets
 3. Future impact

PV market growing (> 0.1 TW in 2018)

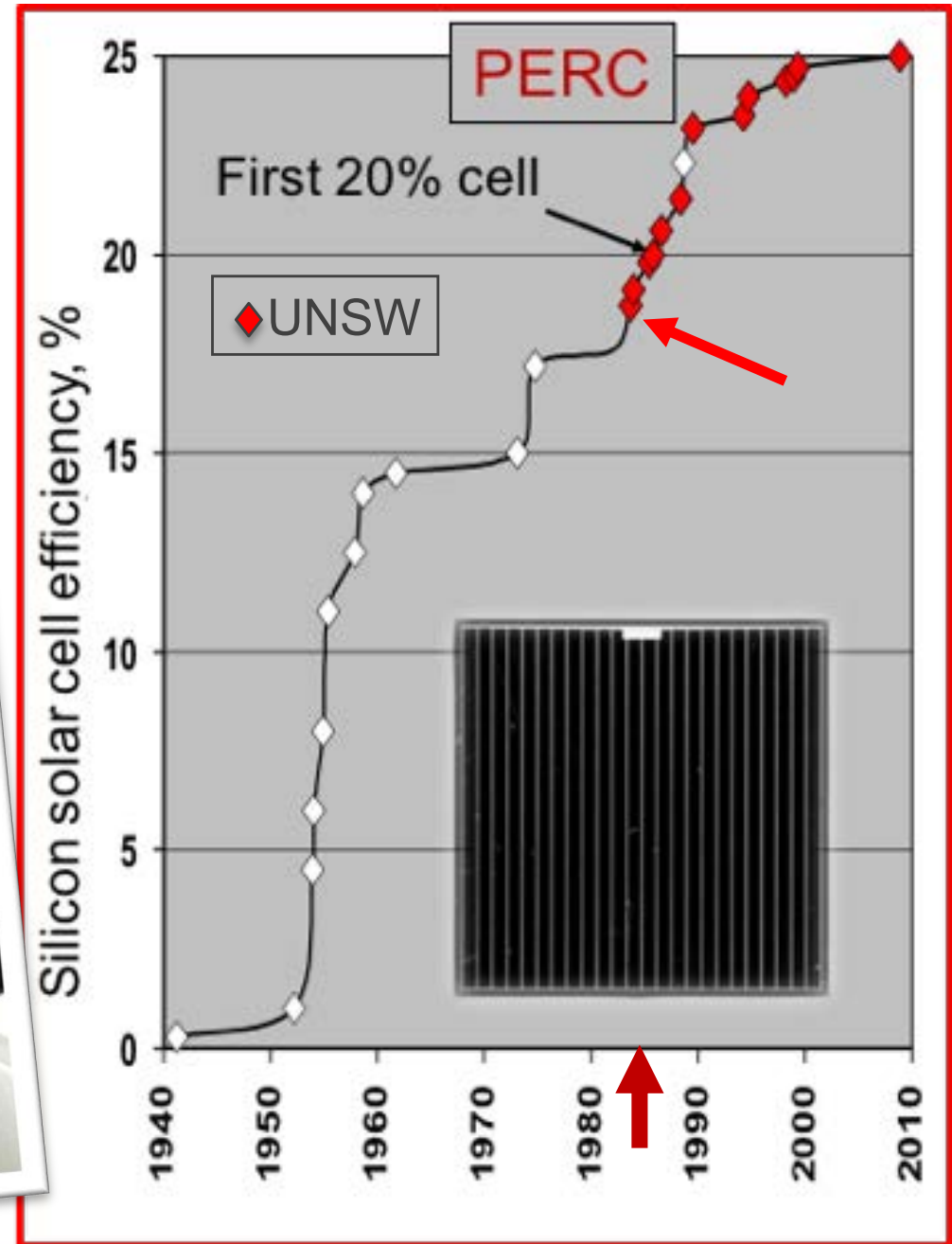


Source: BloombergNEF. Note that the capacity added figures in this chart are preliminary estimates.

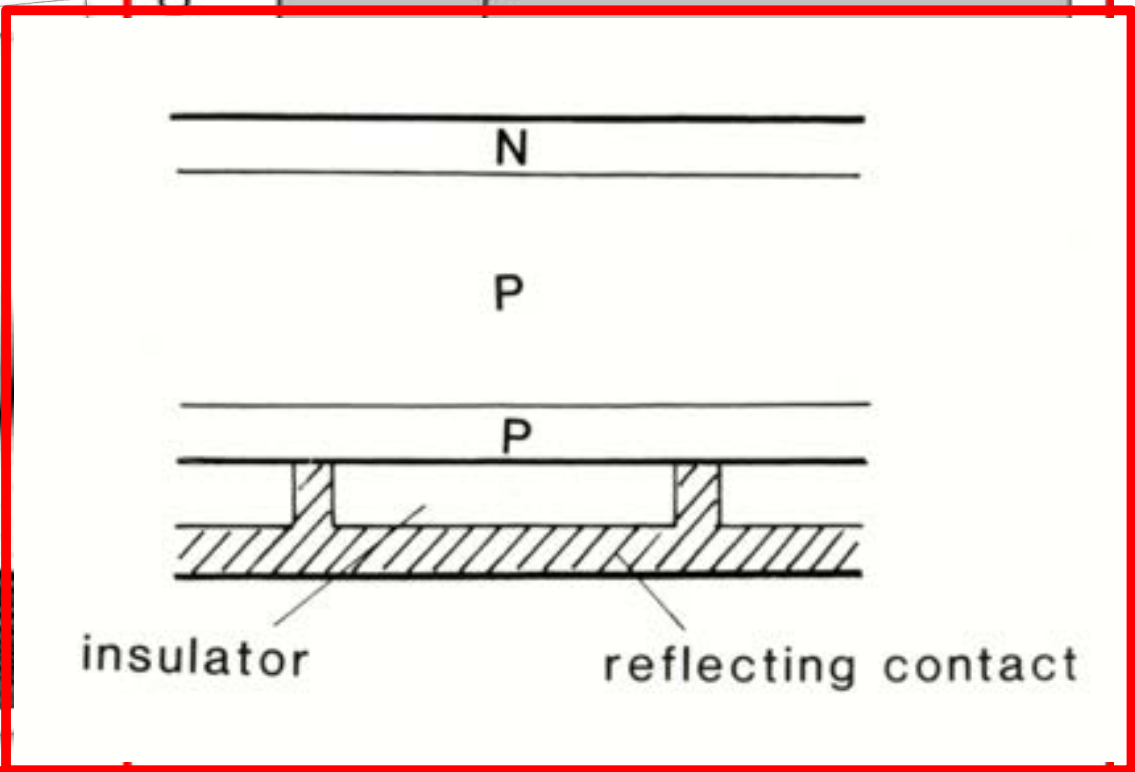
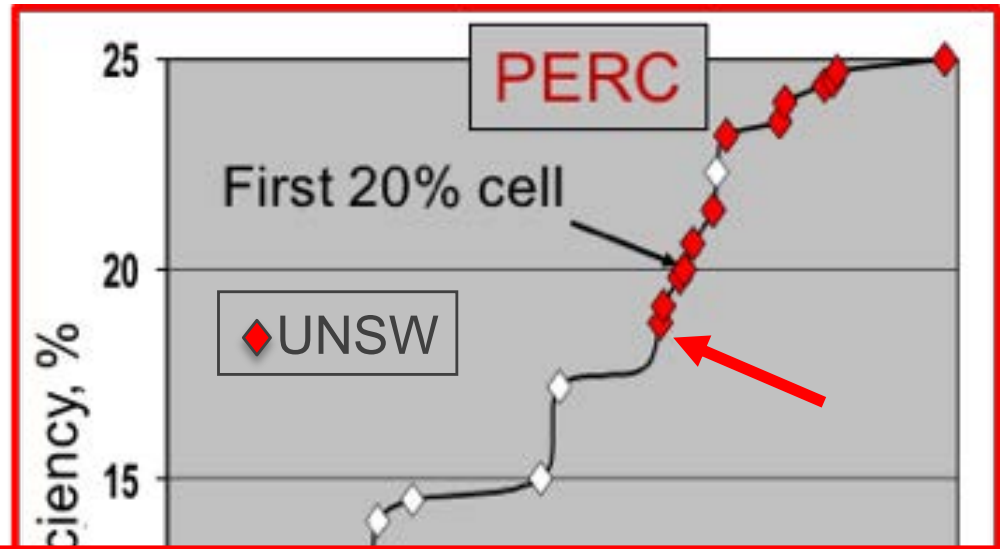
PV market growing (> 0.1 TW in 2018)



1983: First 18% Si cell

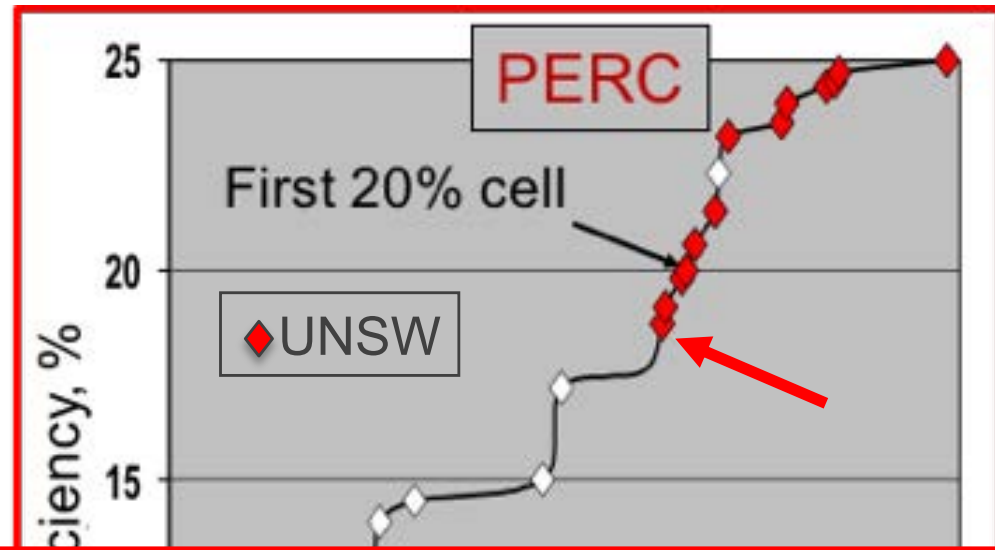


1983: First 18% Si cell
1983: PERC cell invented



M.A. Green et al., "Ultimate Performance Silicon Solar Cells", Final Report, NERDDP Project 81/1264, Jan. 82 - Dec. 83 (dated Feb. 1984).
M.A. Green, "High Efficiency Silicon Solar Cells", Proposal in response to RFP RB-4-04033, SERI (now NREL), March 1984.

1983: First 18% Si cell
1983: PERC cell invented



22.8% efficient silicon solar cell

Andrew W. Blakers, Aihua Wang, Adele M. Milne, Jianhua Zhao, and Martin A. Green
*Solar Photovoltaic Laboratory, Joint Microelectronics Research Centre, University of New South Wales,
Kensington 2033, Australia*

(Received 9 May 1989; accepted for publication 18 July 1989)

A new silicon solar cell structure, the **passivated emitter and rear cell**, is described. The cell structure has yielded independently confirmed efficiencies of up to 22.8%, the highest ever reported for a silicon cell.

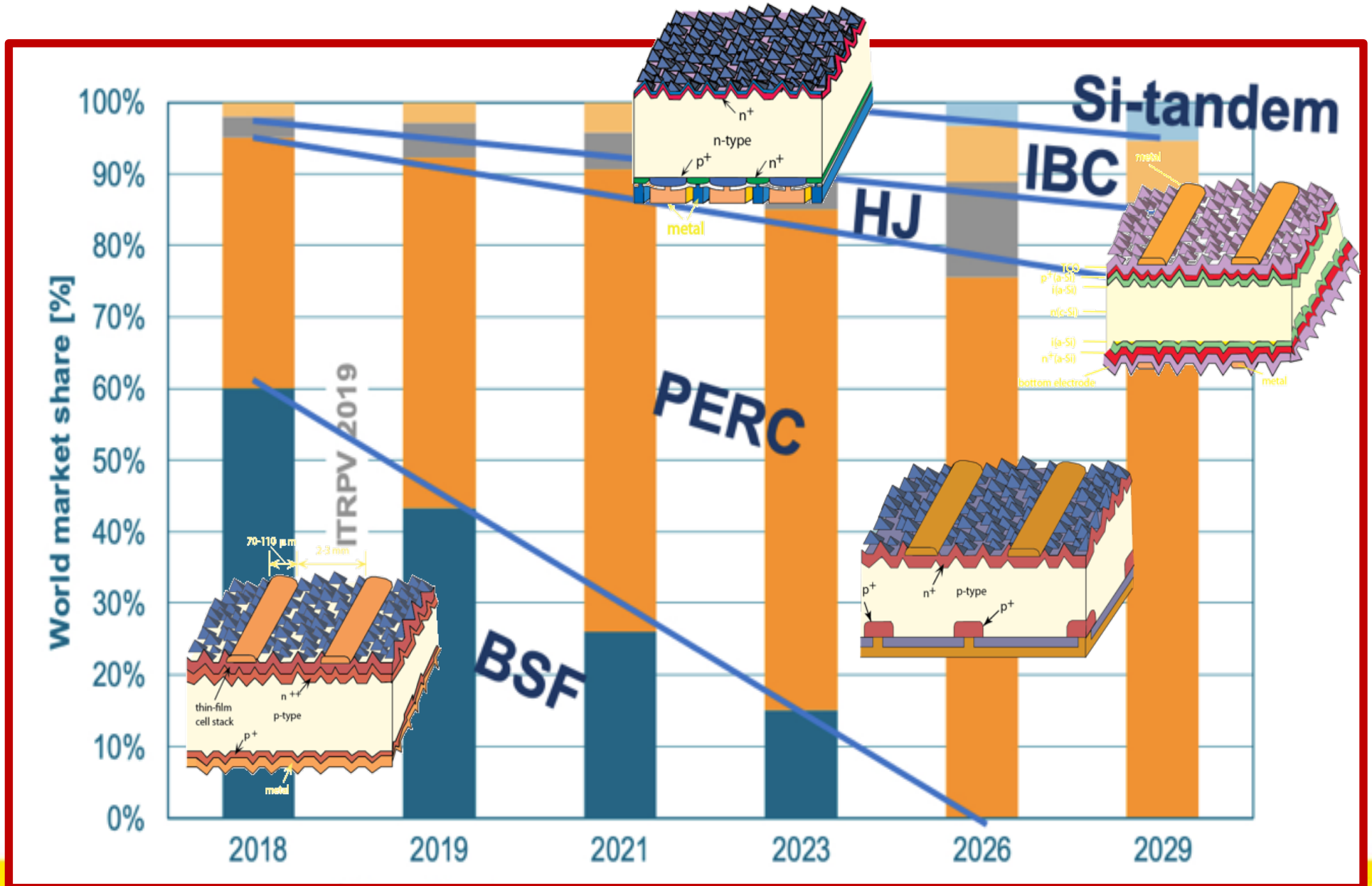
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Appl. Phys. Lett. 55 (13), 25 September 1989

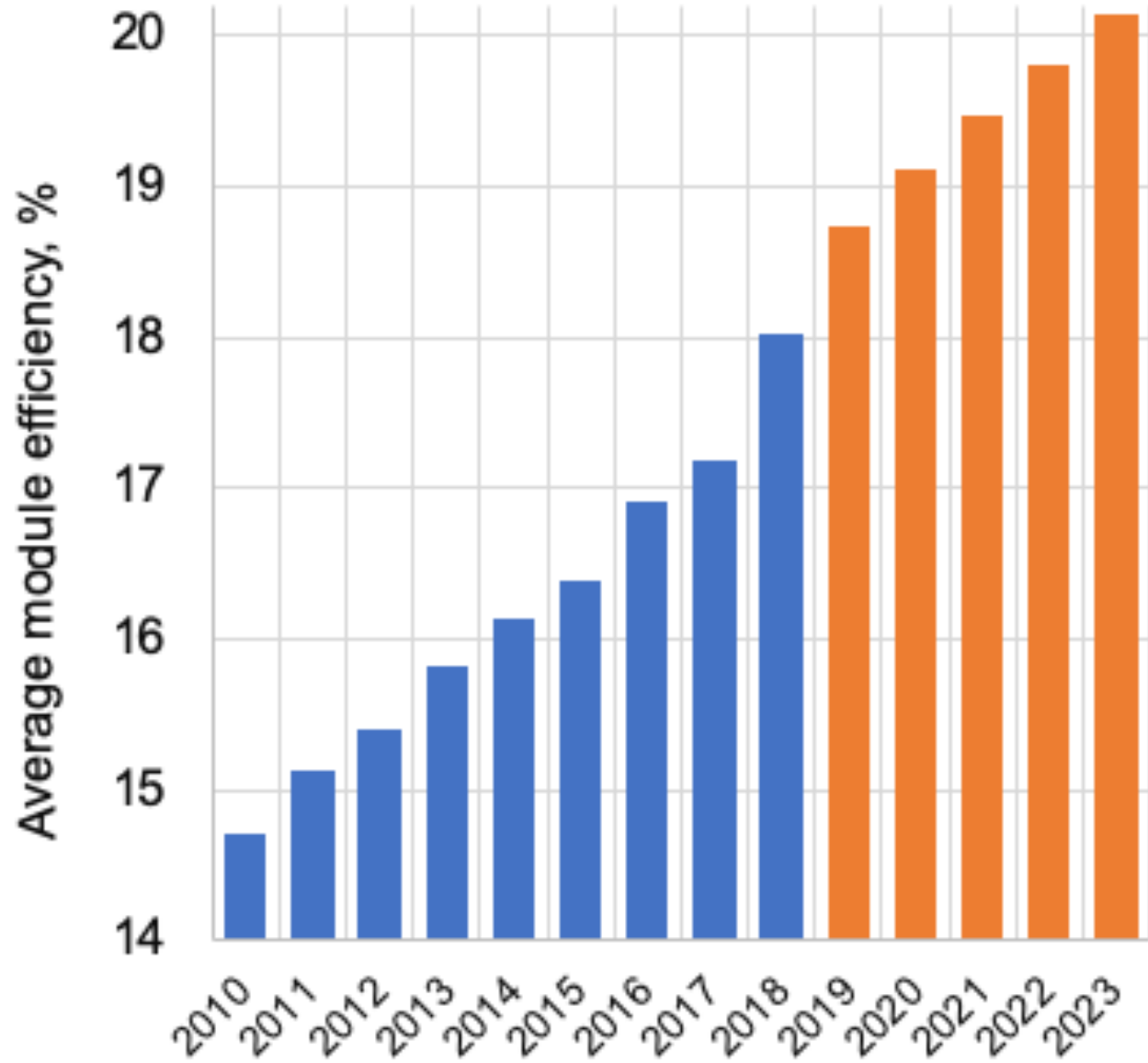
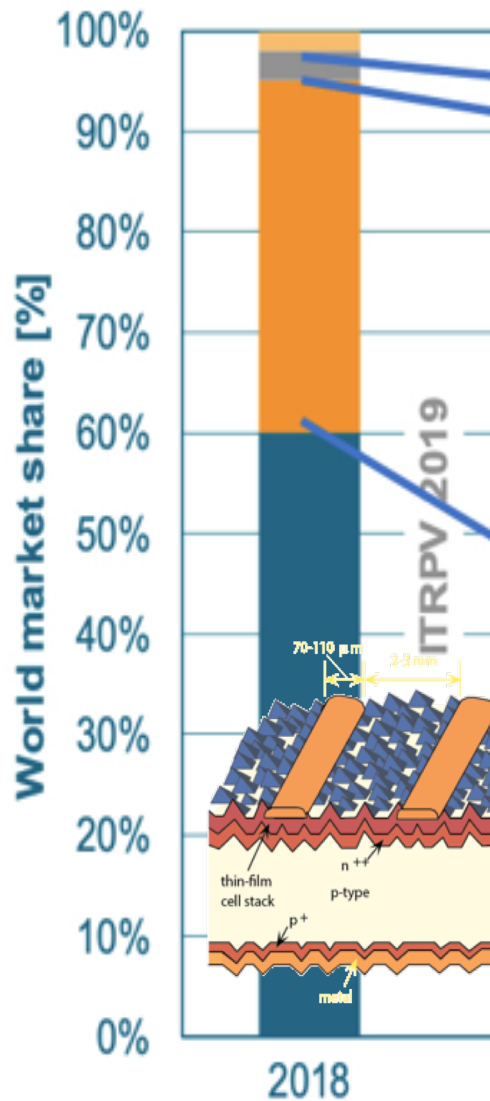
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PERC market share



PERC market share

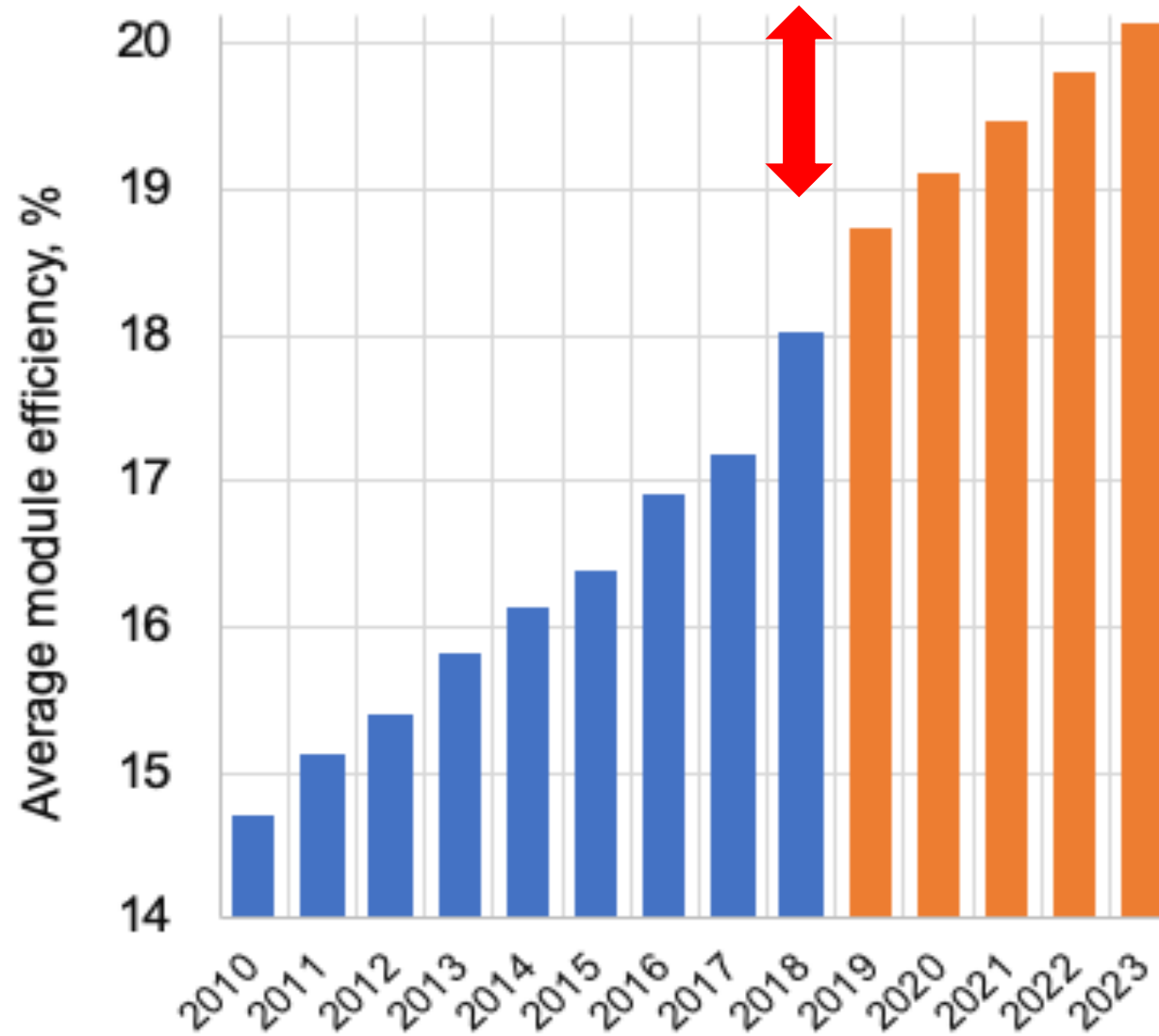


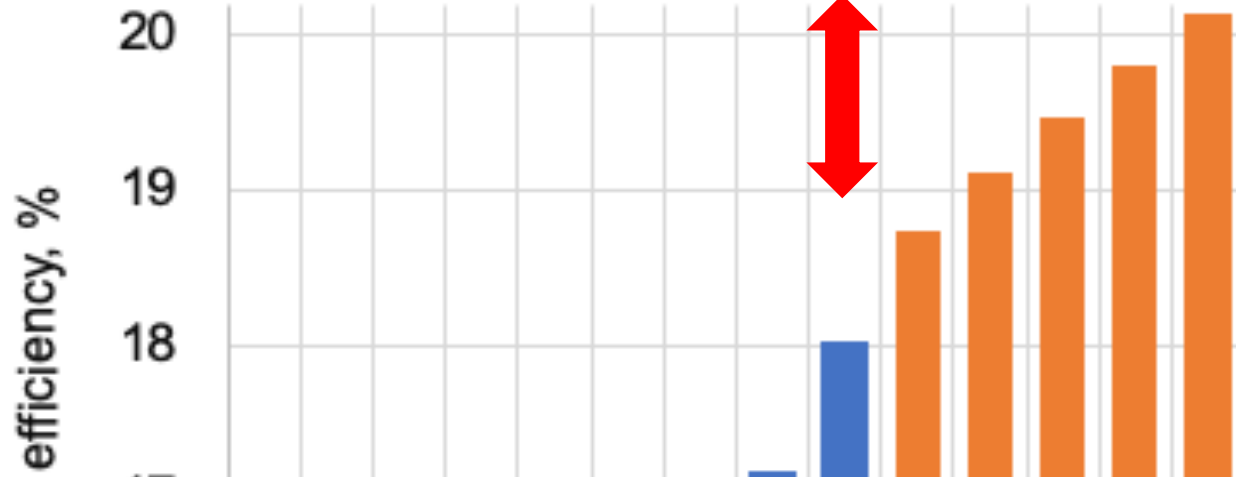


Bifacial PERC half-cells



Bifacial





10-year Warranty for Materials and Processing;
30-year Warranty for Extra Linear Power Output

-0.45%
30-year Power
Warranty Annual
Power Attenuation
-0.45%

84.95%



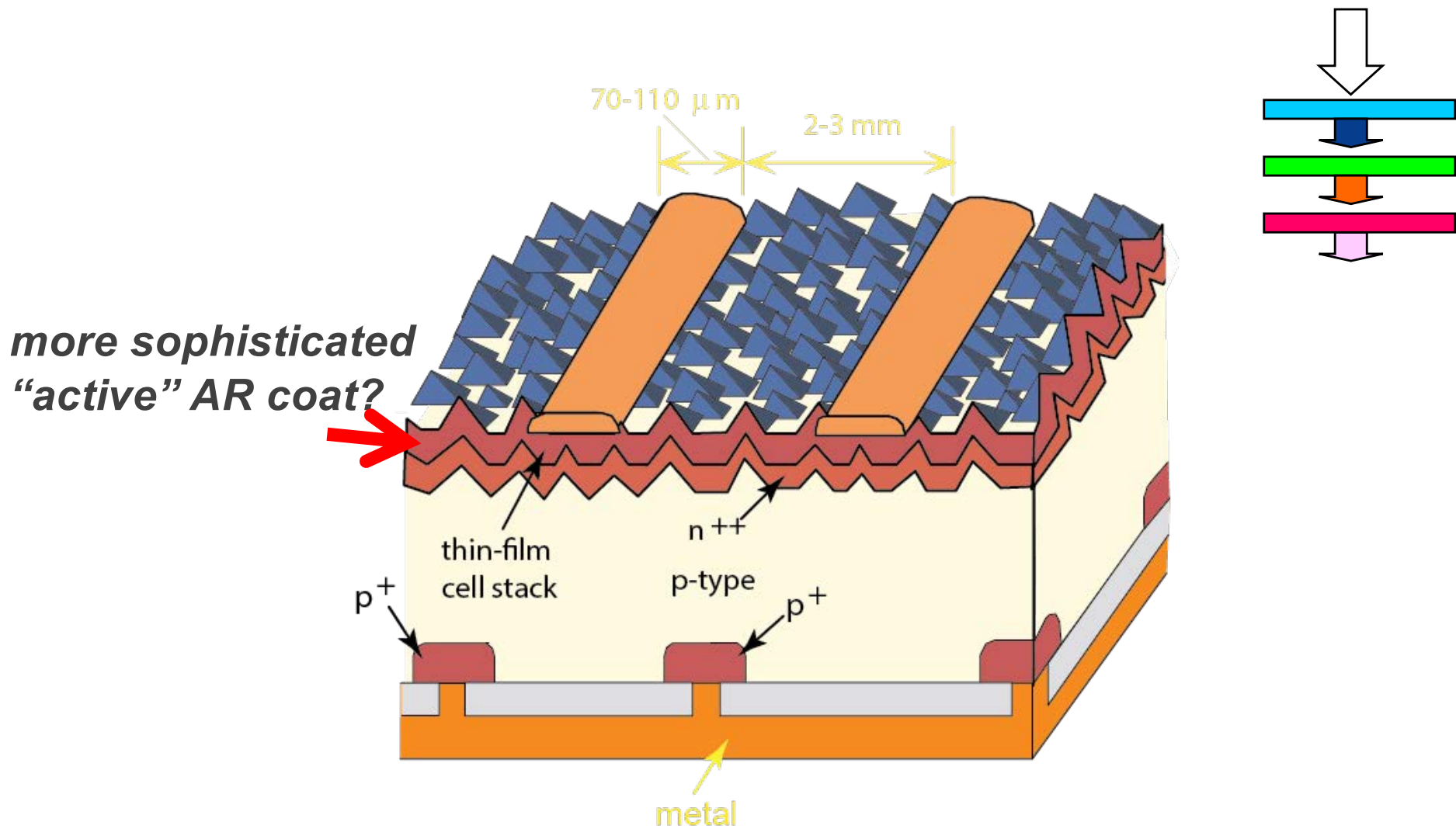


1996 Honda Dream





Q: What ideally comes after PERC?



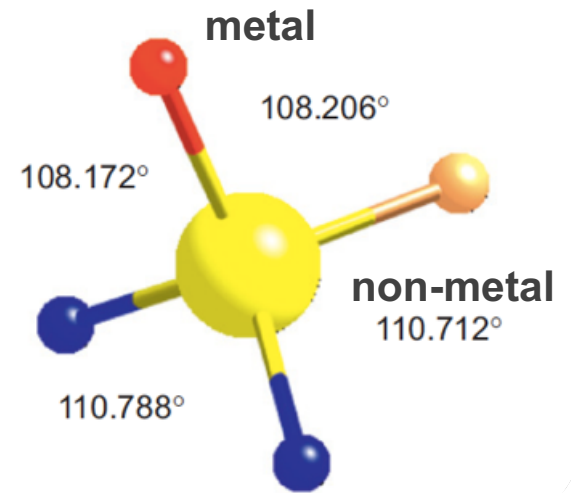
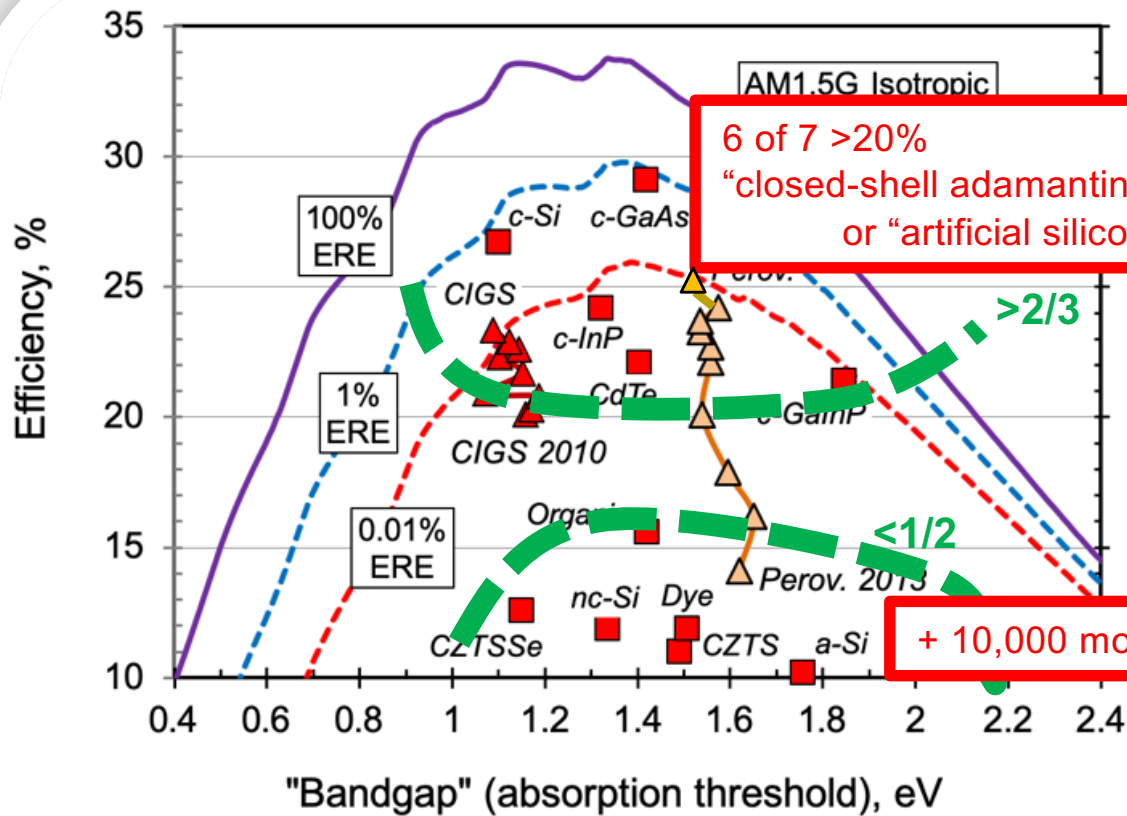
Tandem PERC! – but what thin-film material?

Green elements: Abundant and benign

IA 1 H																	VIII B 2 He						
3 Li																	4 Be	5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	I A	I I A	I I I A	I V A	V A	V I A	V I I A	V I I I A			I B	12 Mg	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar					
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr						
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe						
55 Cs	56 Ba	57-71 <small>lanthanides</small>	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn						
			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu						

rare	RoHS	toxic	OK
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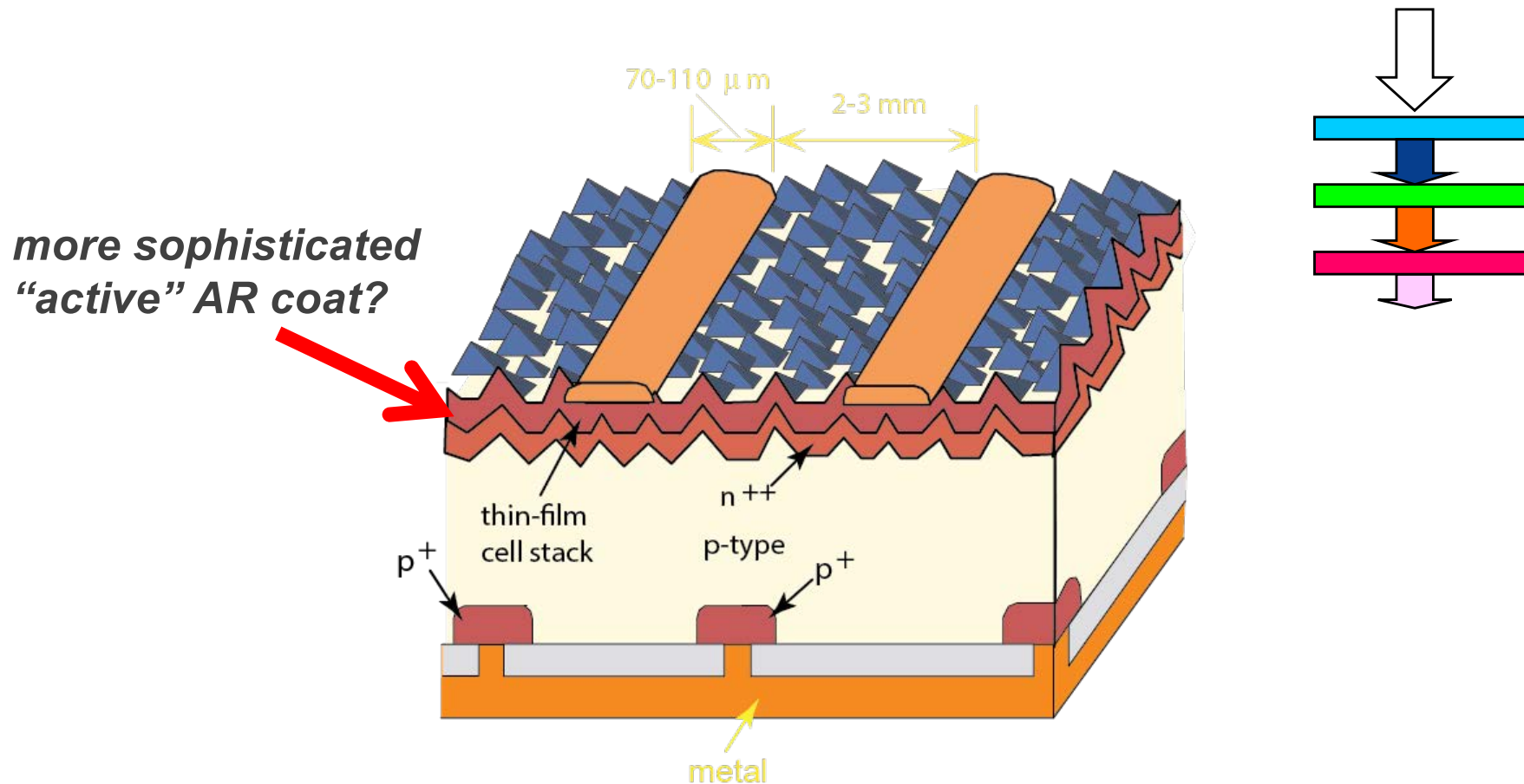
Green elements: Abundant and benign



Pb	Bi	Po	At	Rn
68	69	70	71	
Er	Tm	Yb	Lu	

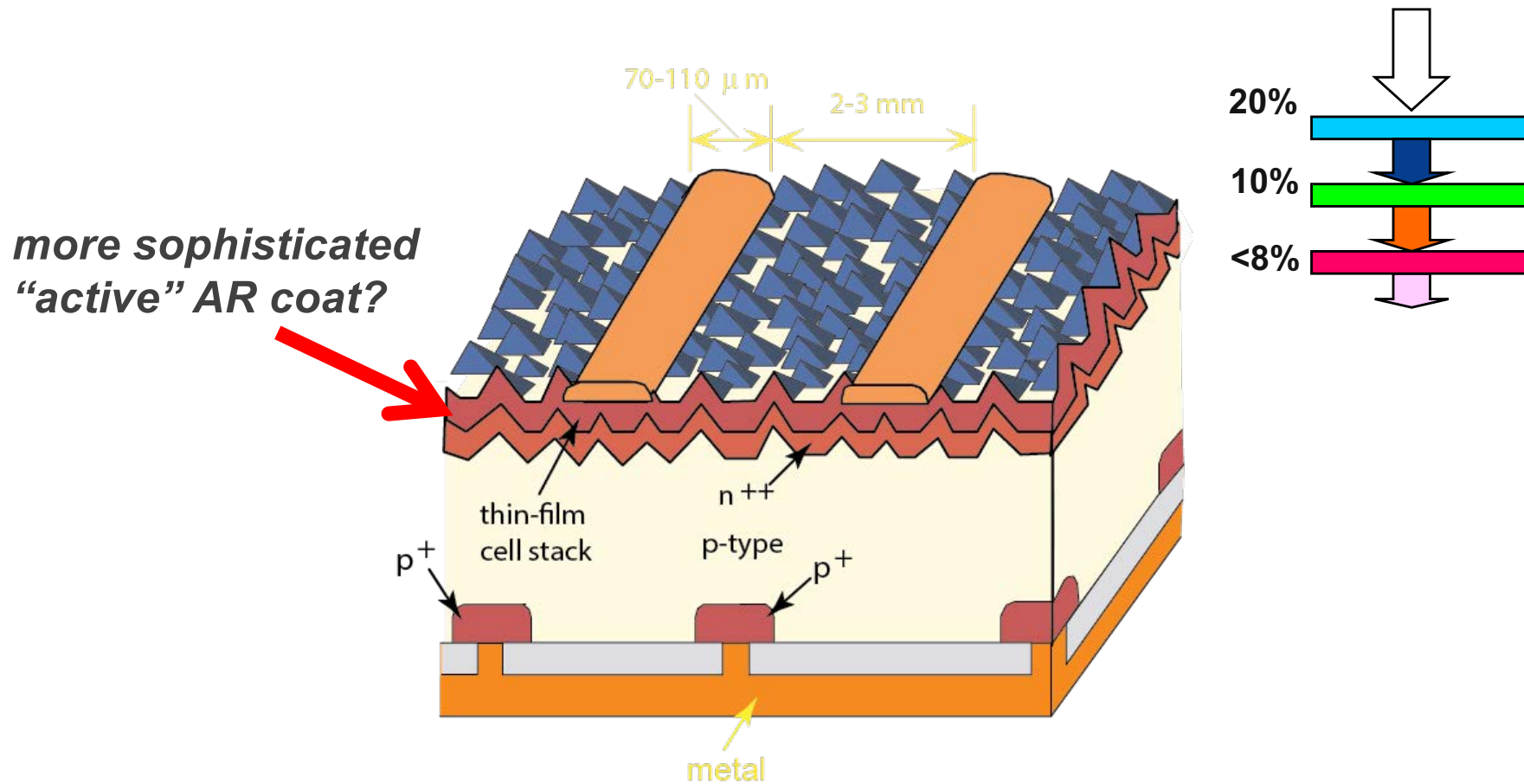
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What comes after double-junction PERC?



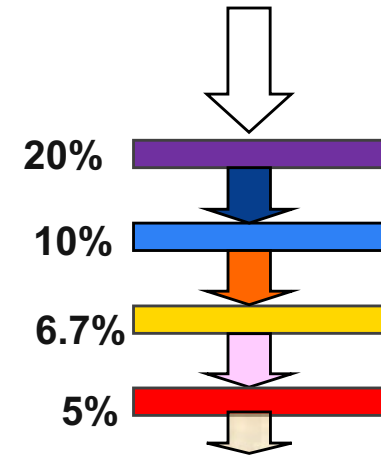
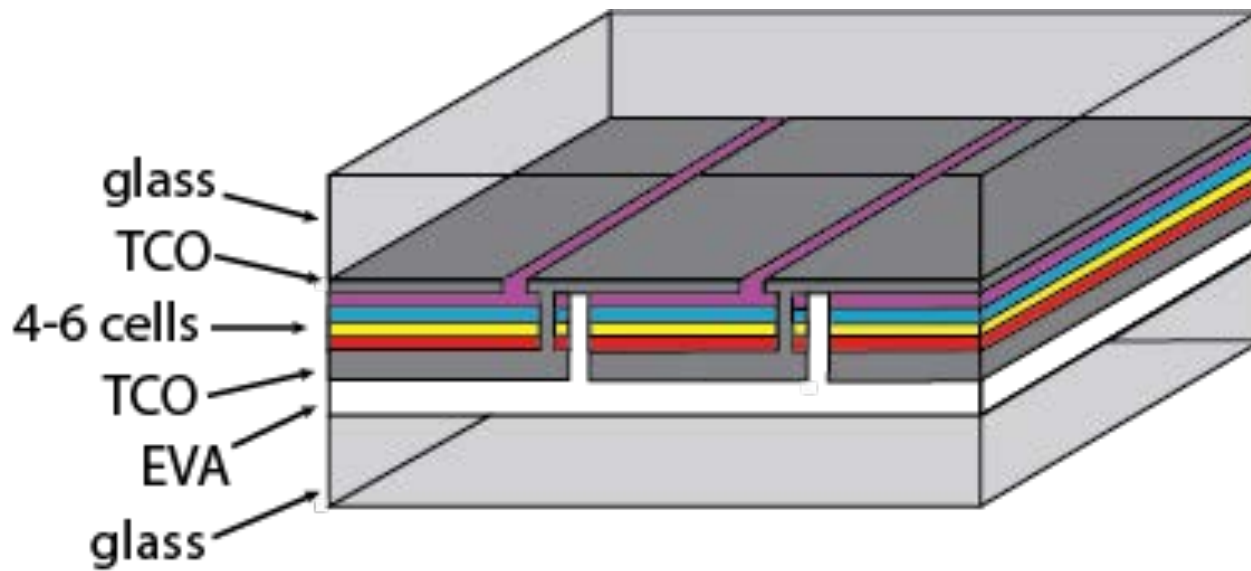
Triple-junction PERC! – middle cell nearly for free!

What comes after double-junction PERC?



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

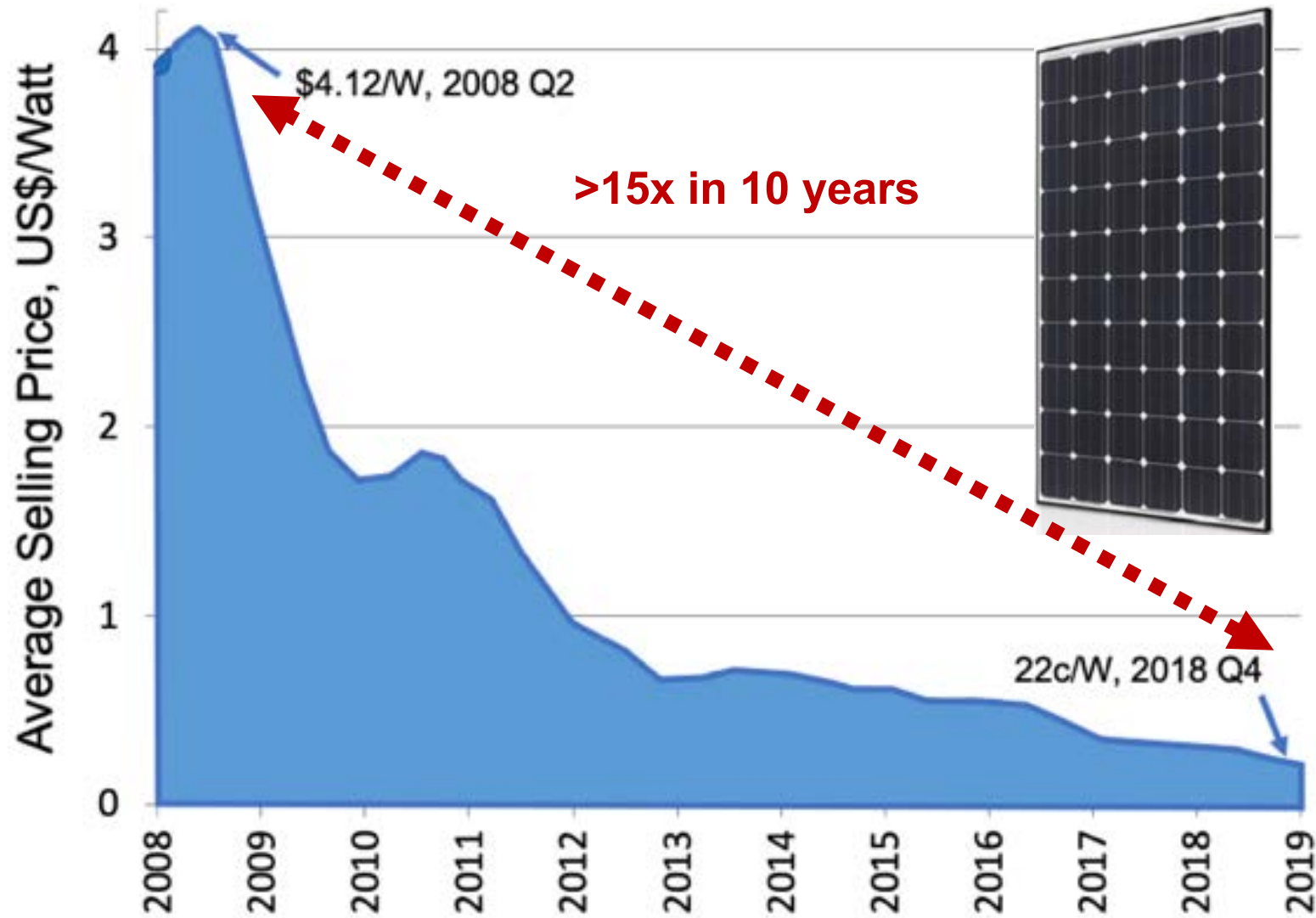
What comes after triple-junction PERC?



Quadruple-junction thin-film!

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1. Technology
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Module cost / watt



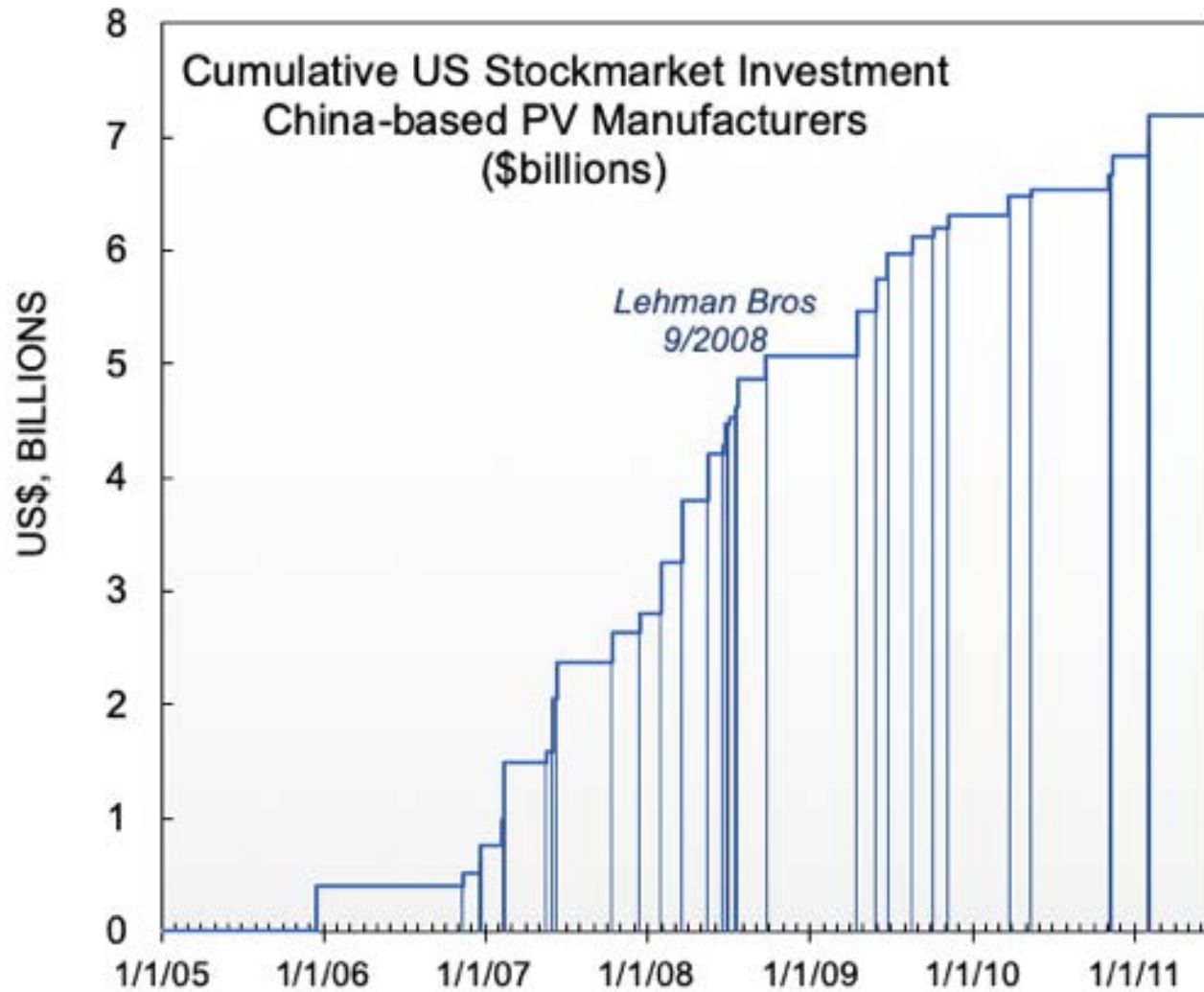
Zhengrong Shi, 12th PhD student, “First Solar Billionaire”



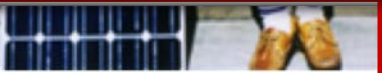
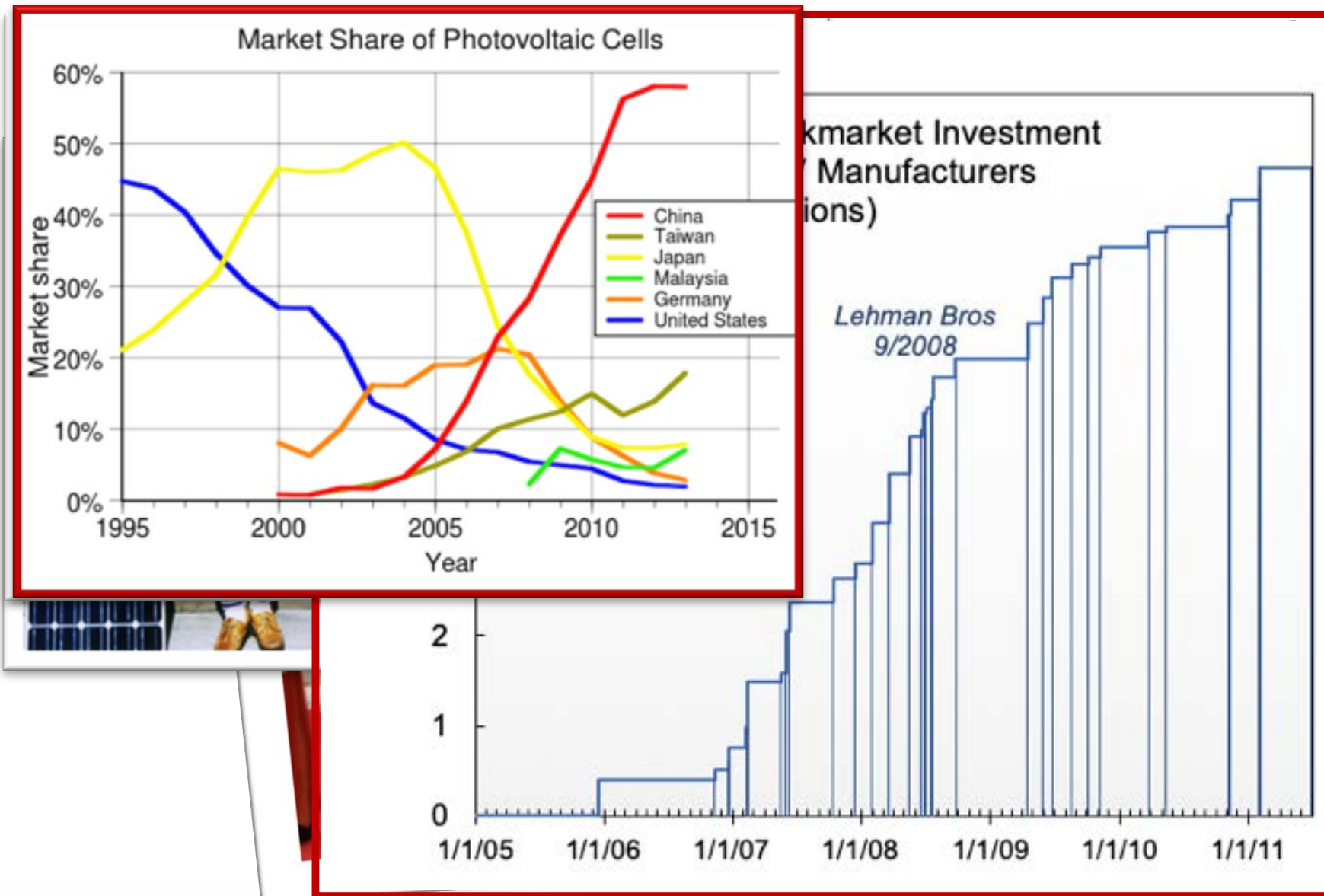
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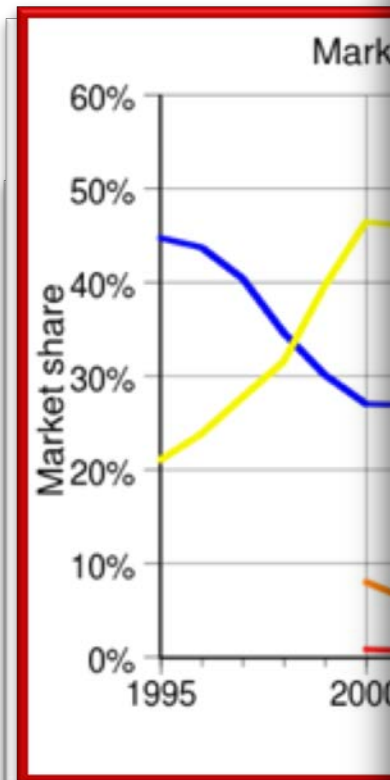
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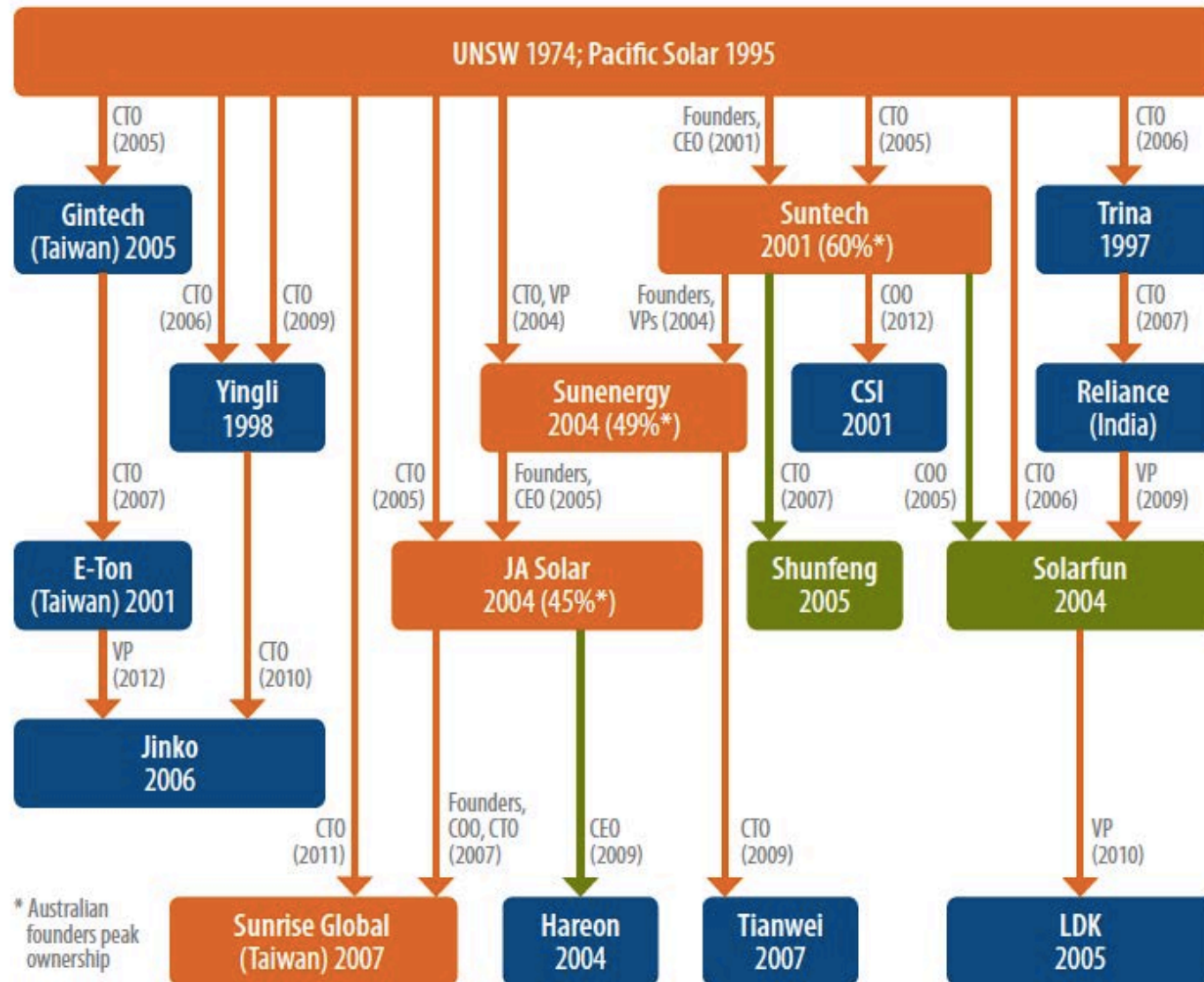
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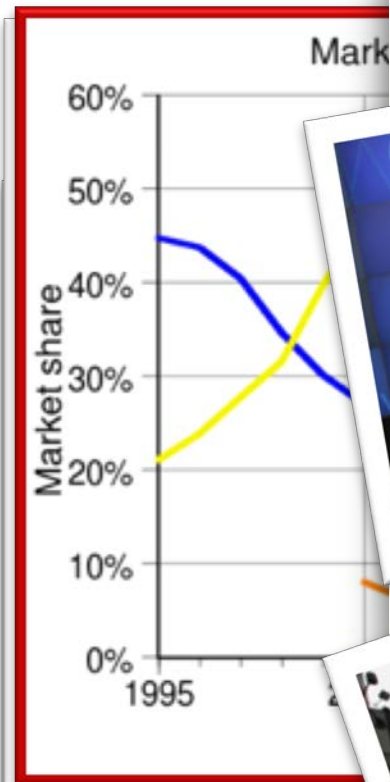
Australian links to some of the key firms in the Chinese PV Industry



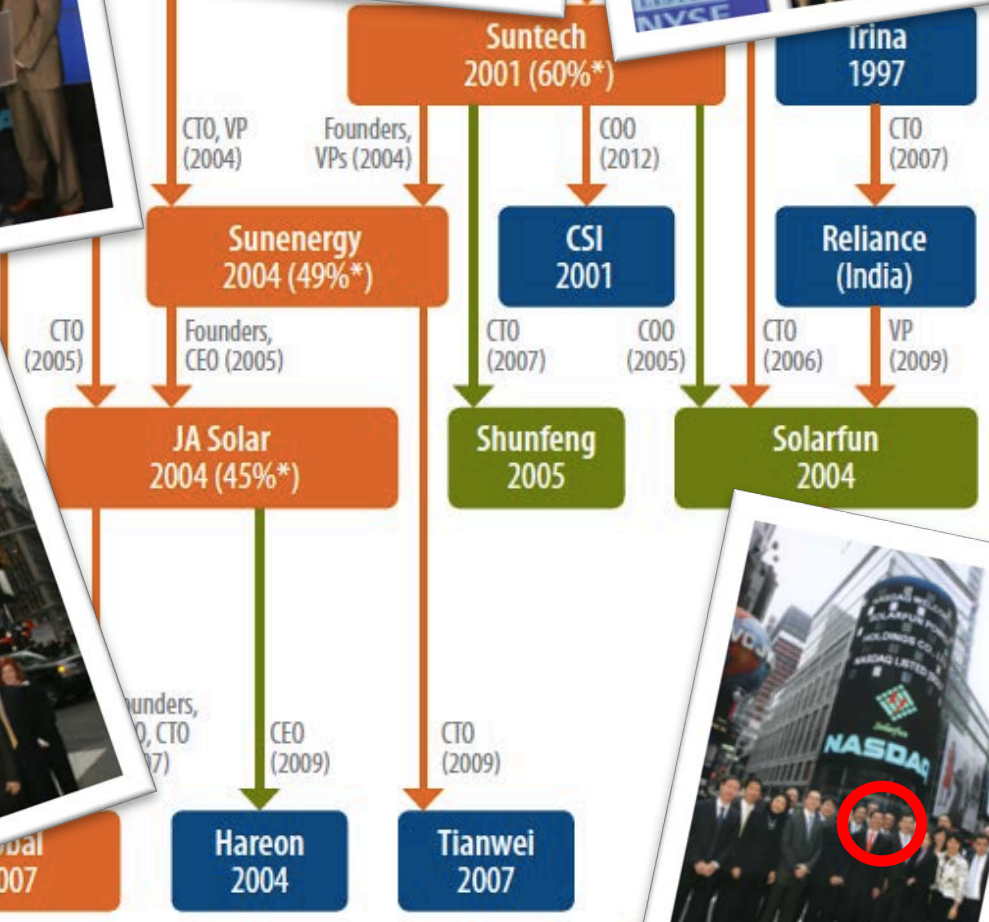
Orange represents UNSW/Pacific Solar trained or co-founded, green represents “second generation” linkages, and blue “others”.

Source: UNSW

Zhengrong Shi, 12th P

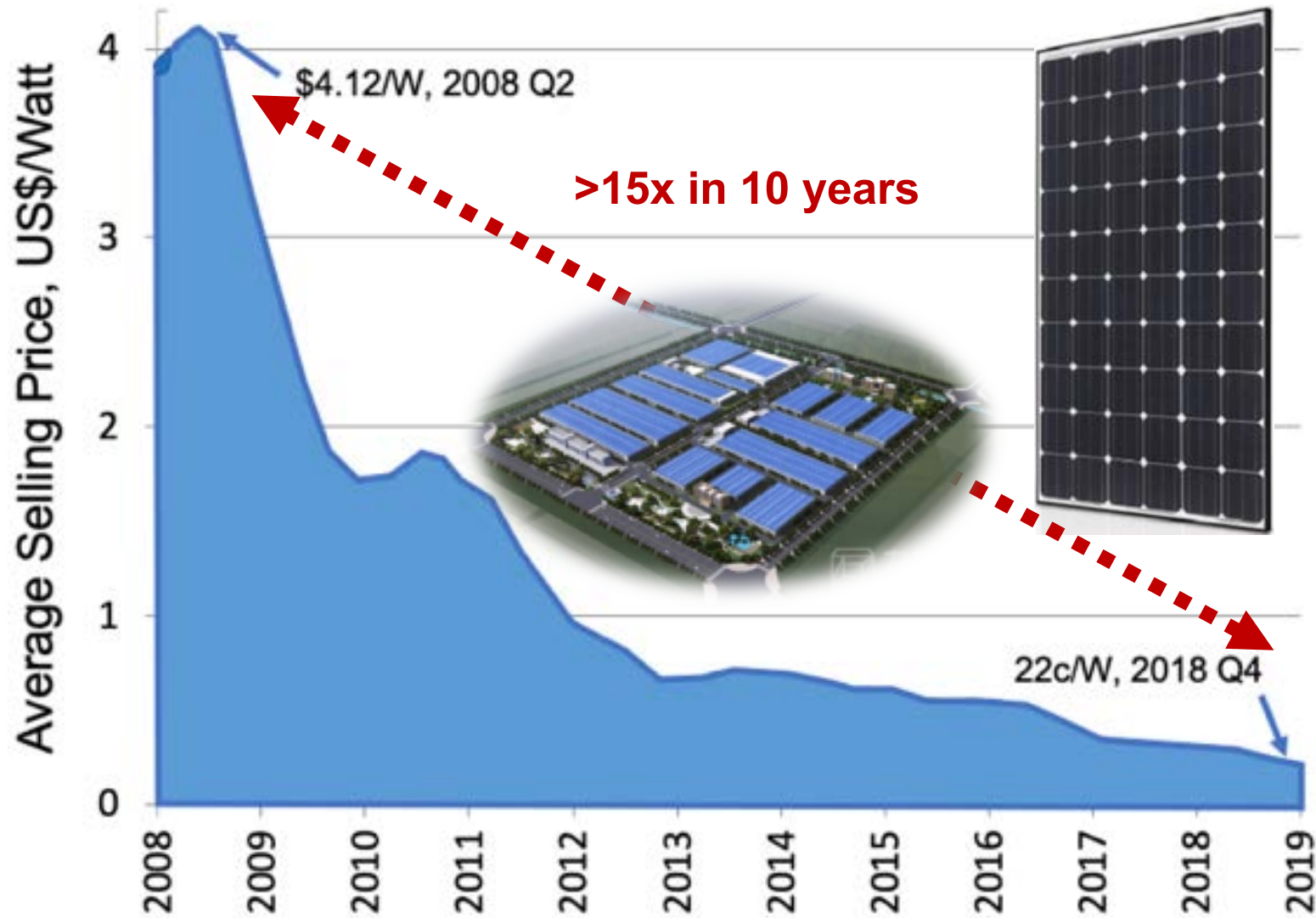


Australian links to some of

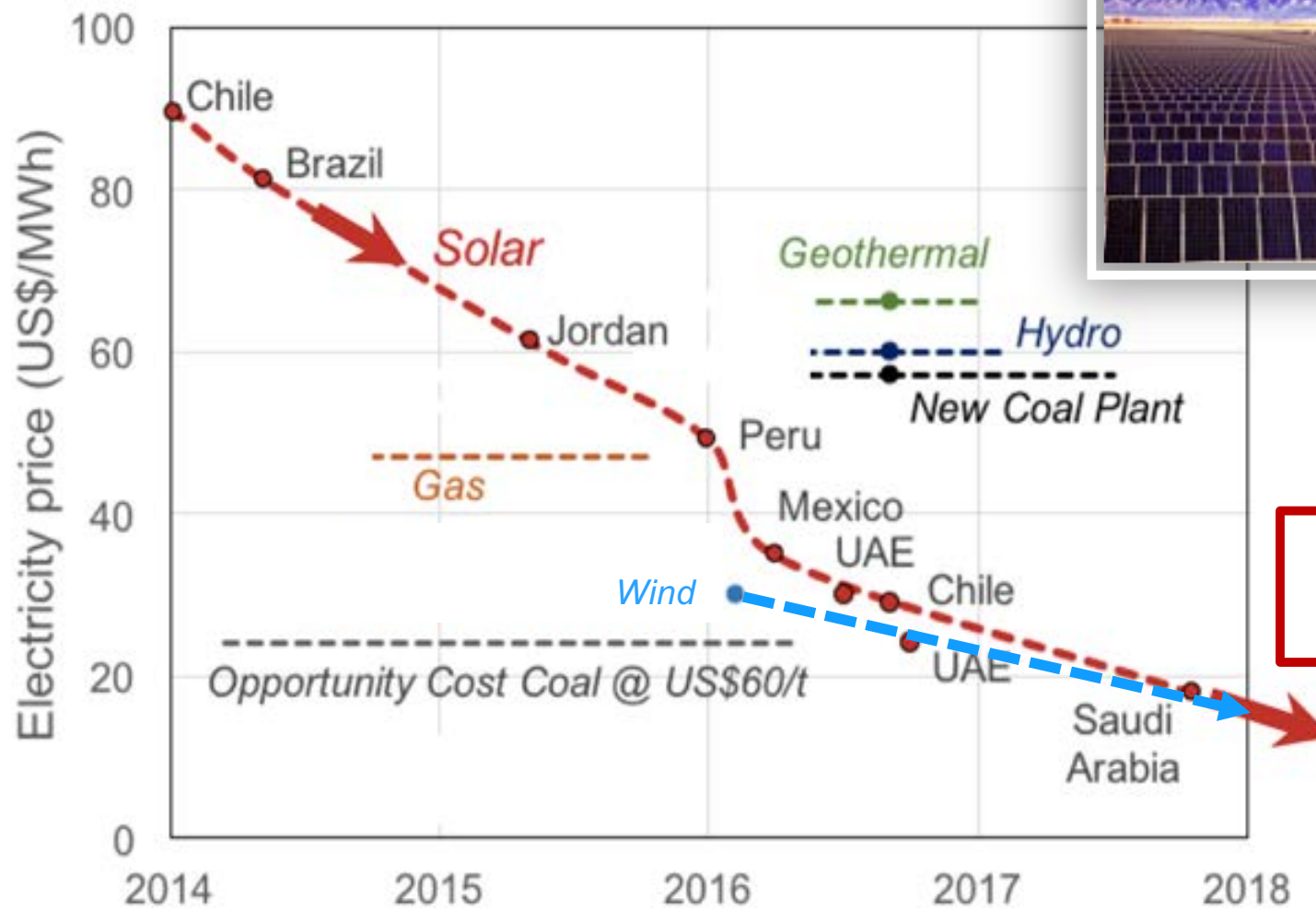


Orange represents UNSW/Pacific Solar trained or co-founded, green represents "second generation"

Module cost / watt



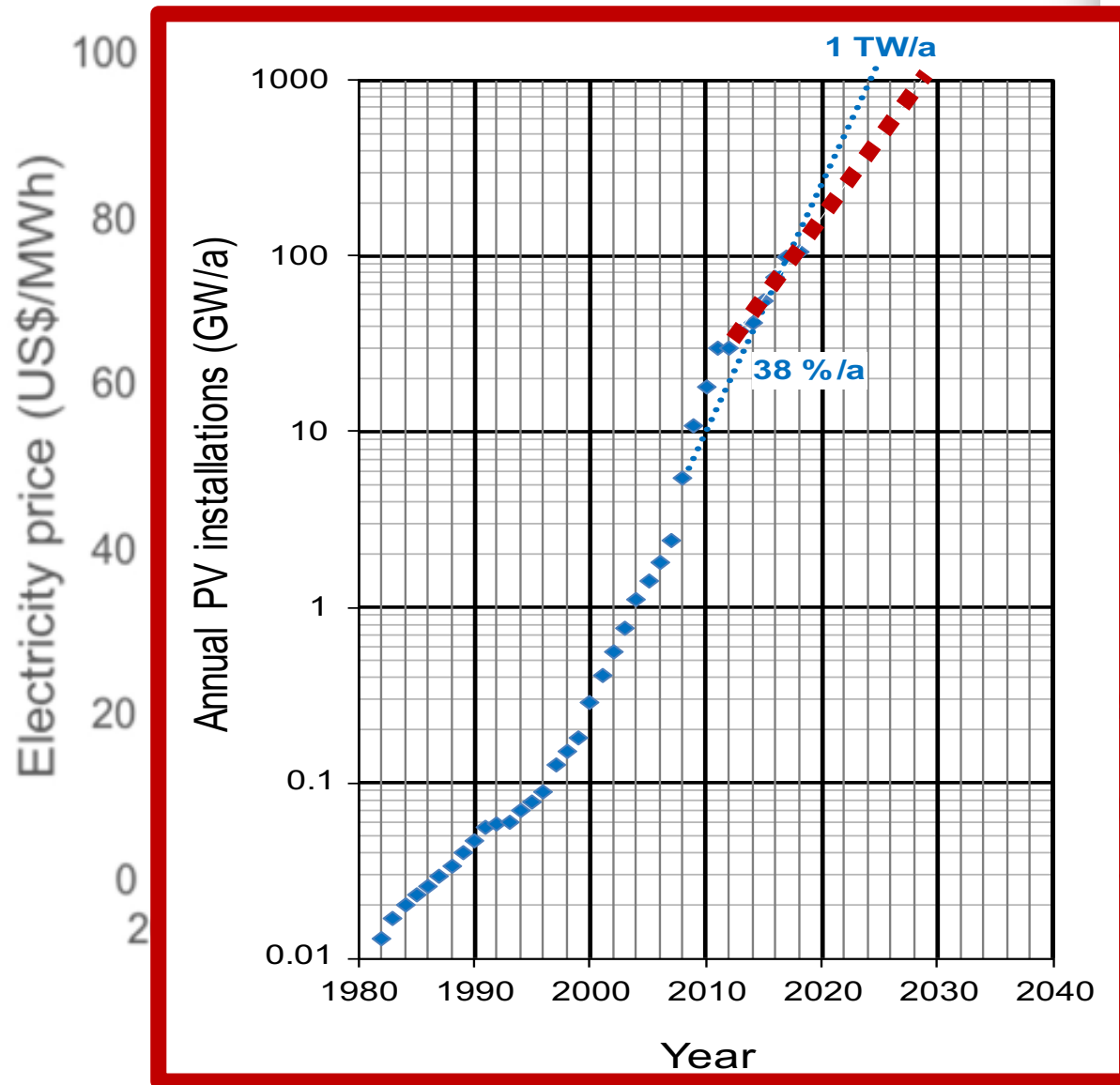
Low bids: power purchase agreements



How low?
\$10/MWh?

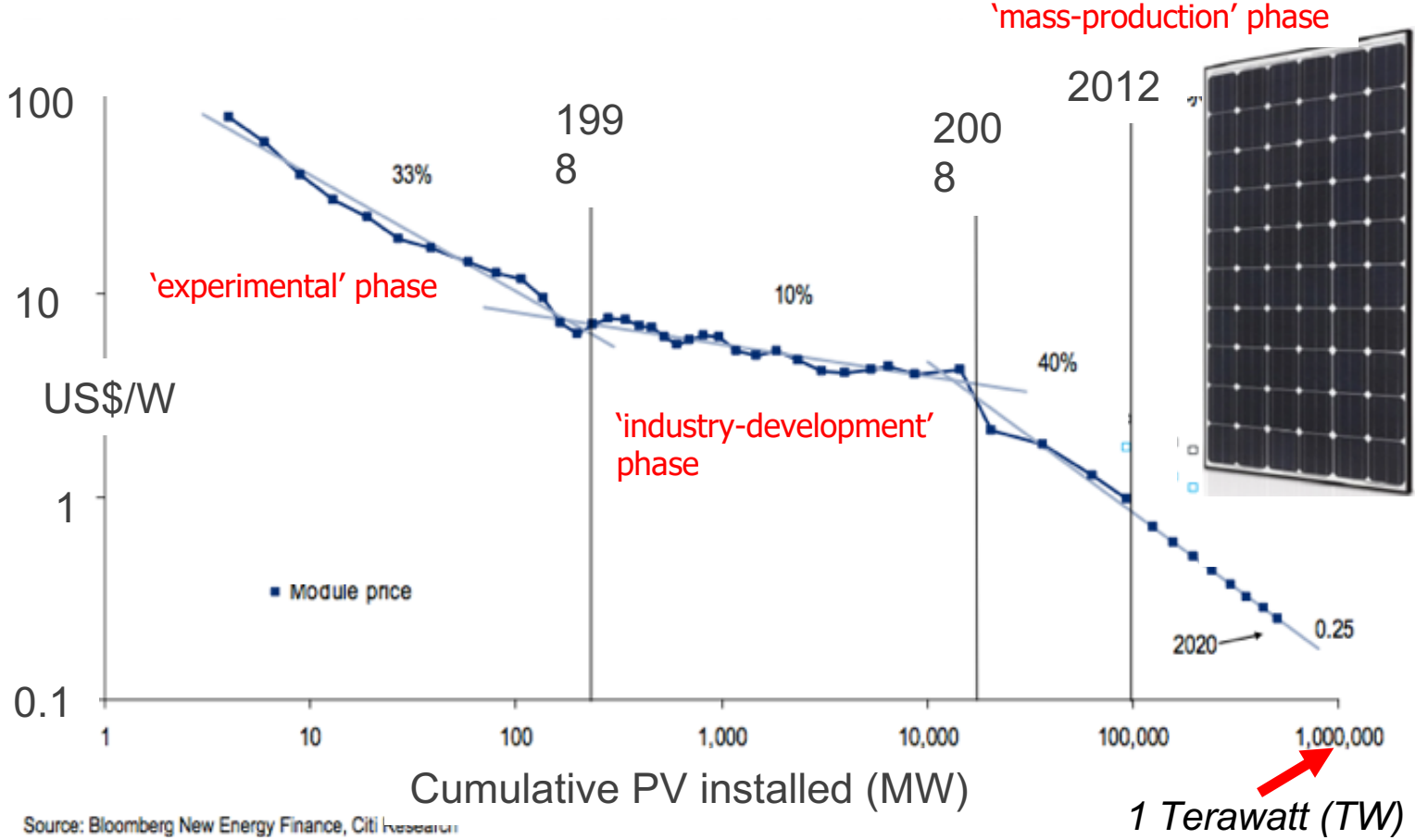
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Low bids: power purchase agreements

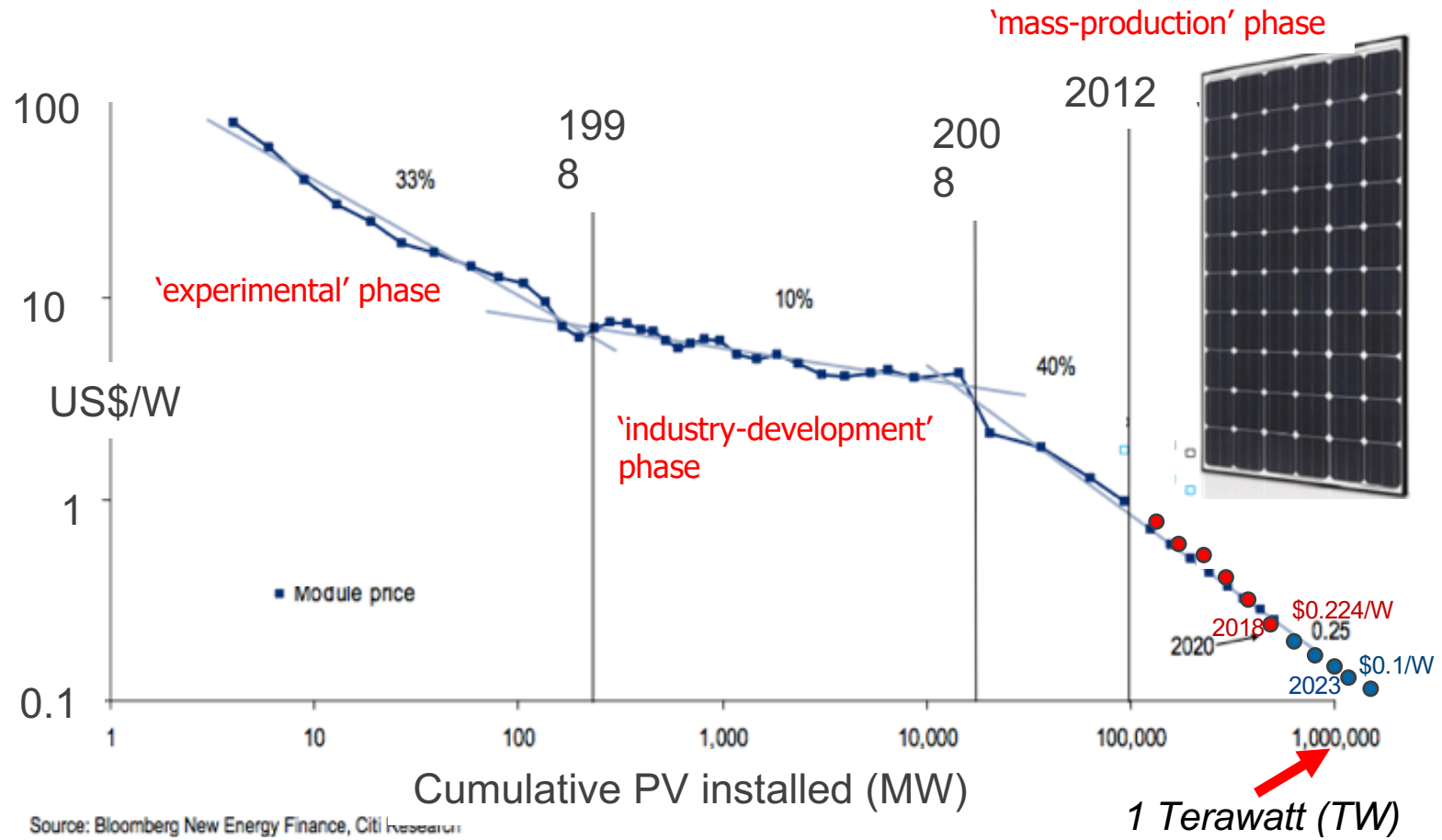


How low?
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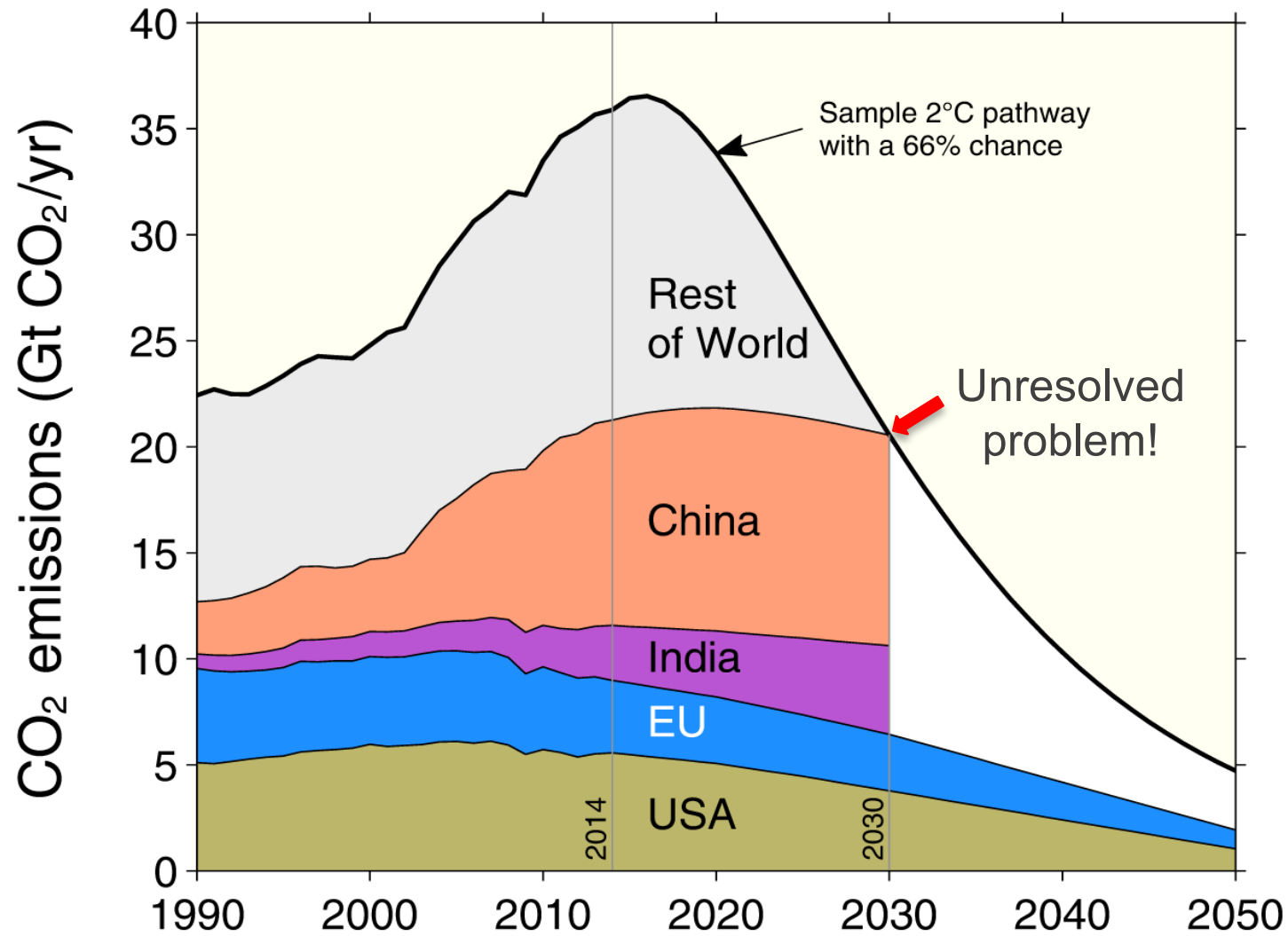
Learning curve



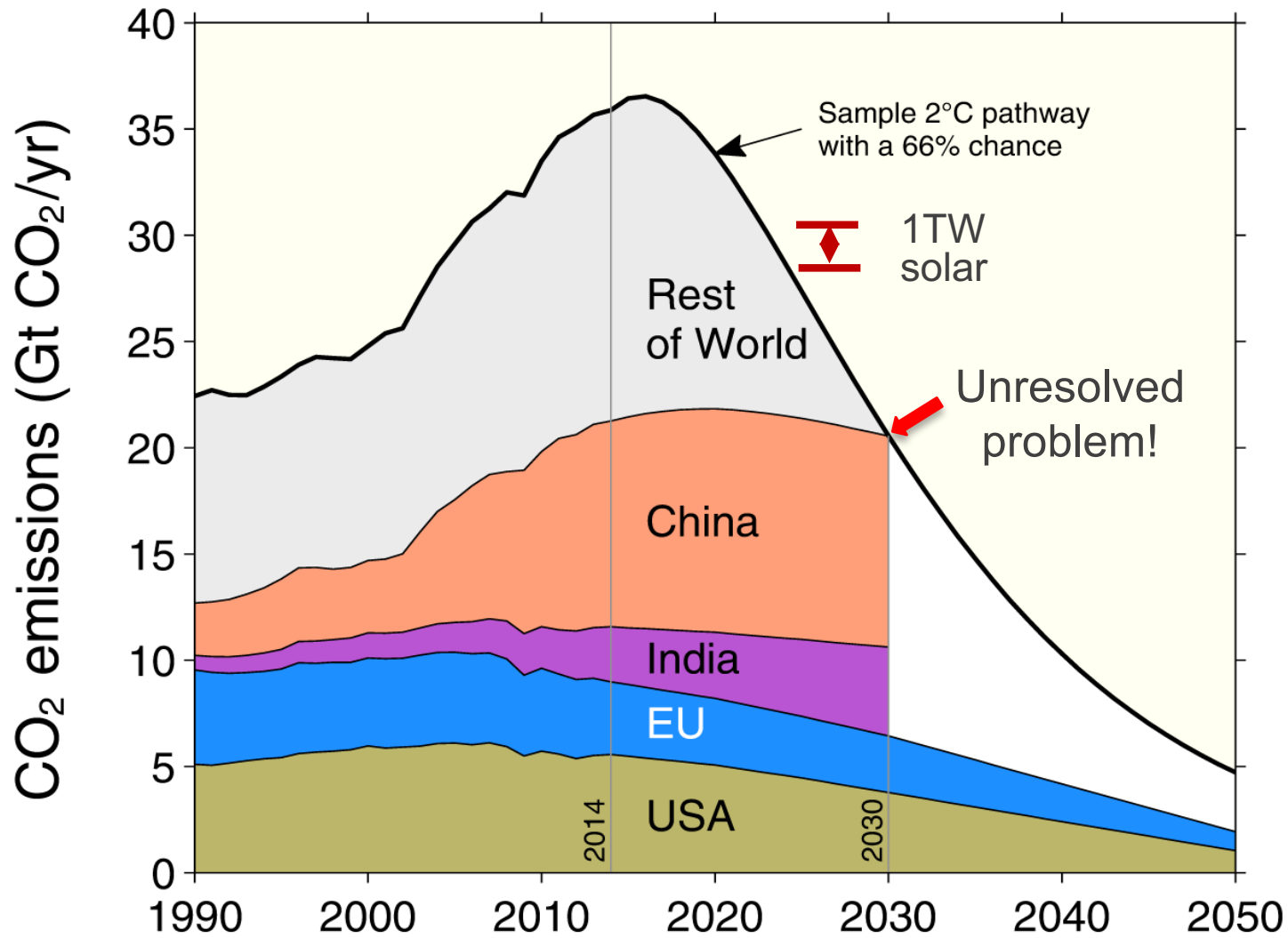
Learning curve



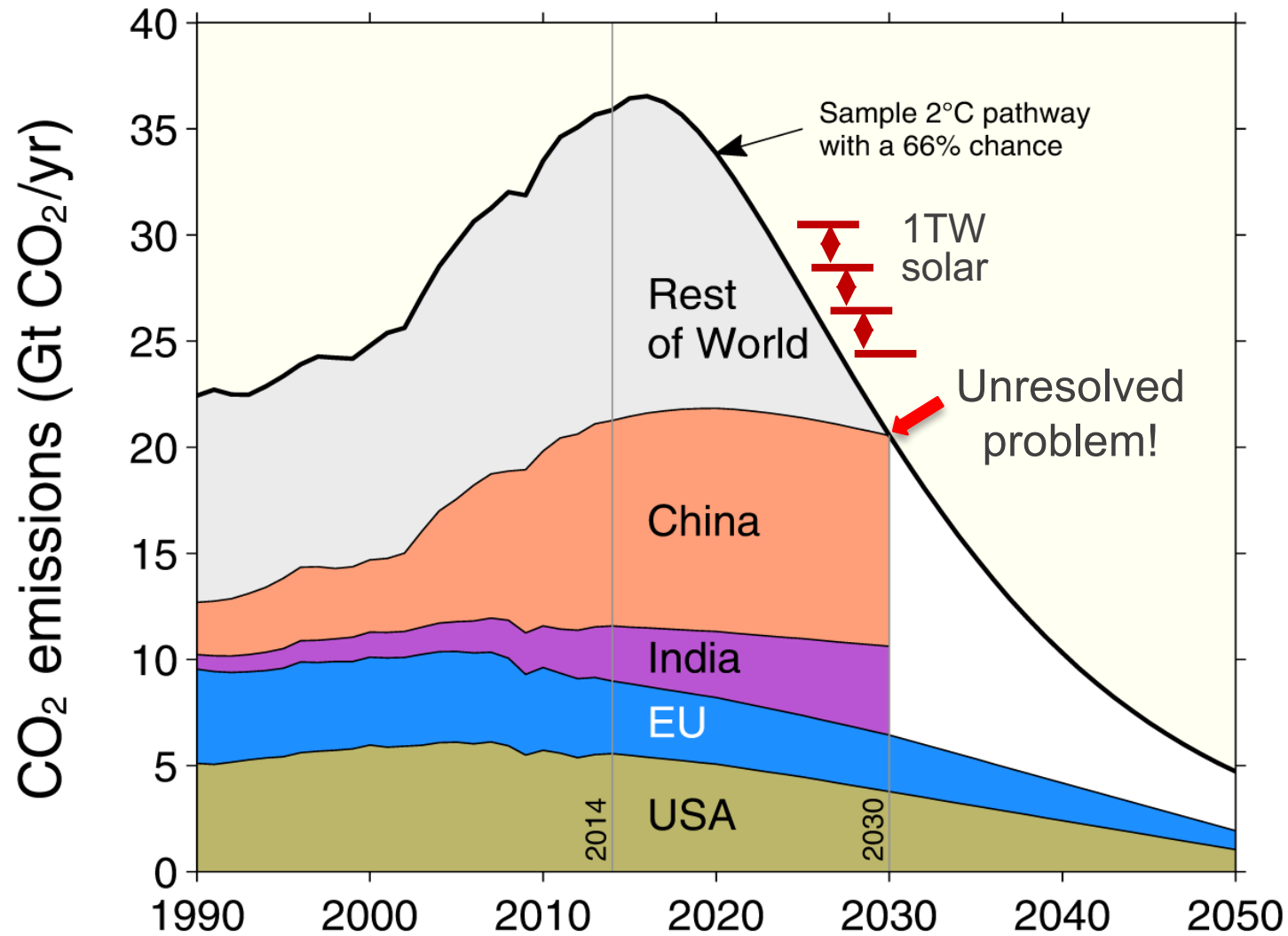
2°C trajectory



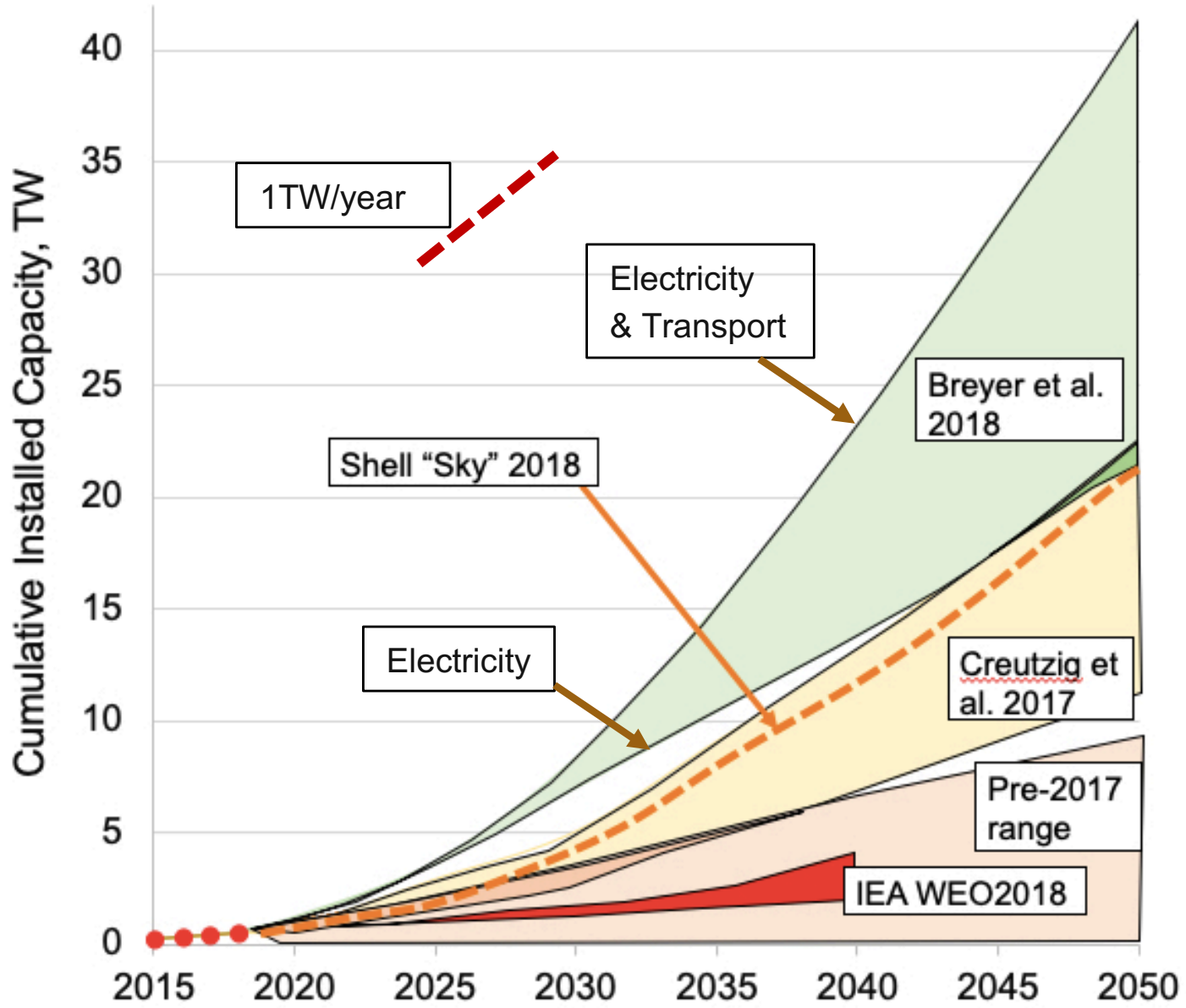
2°C trajectory



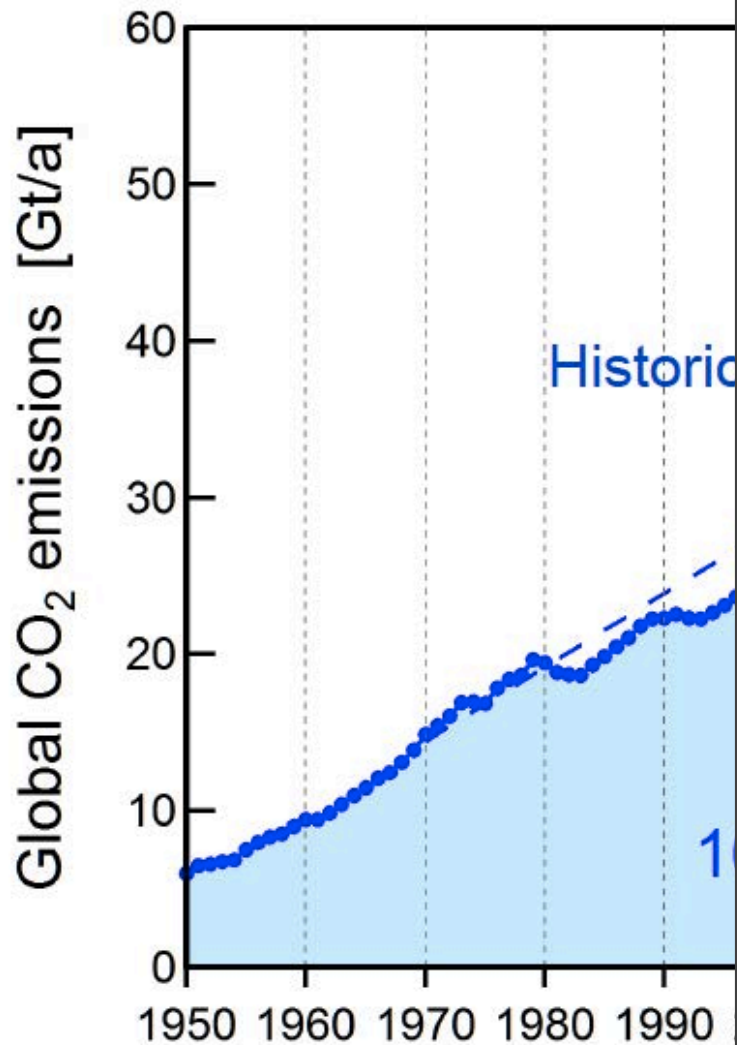
2°C trajectory





Market impact



3. Solar gets CO2 under control

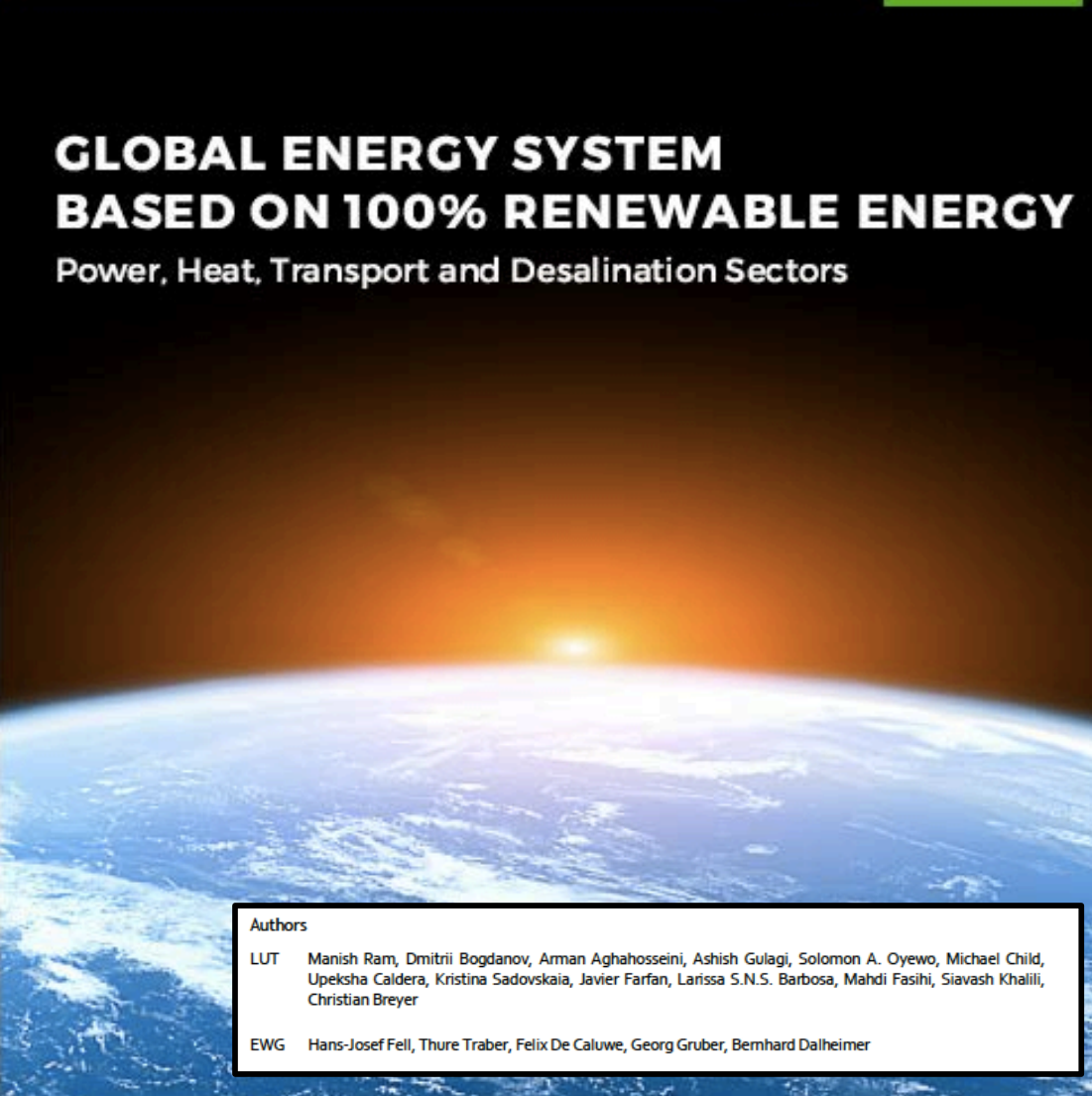


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GLOBAL ENERGY SYSTEM BASED ON 100% RENEWABLE ENERGY

Power, Heat, Transport and Desalination Sectors





Authors

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EWG Hans-Josef Fell, Thure Traber, Felix De Caluwe, Georg Gruber, Bernhard Dalheimer

Study by

 LUT University

 ENERGYWATCHGROUP

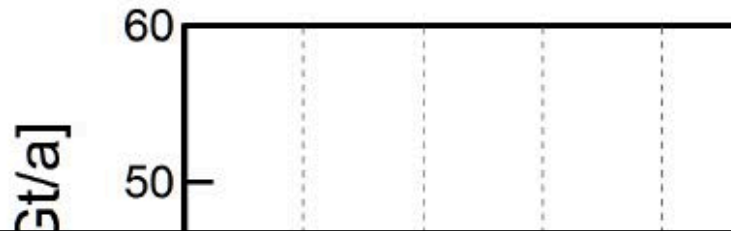
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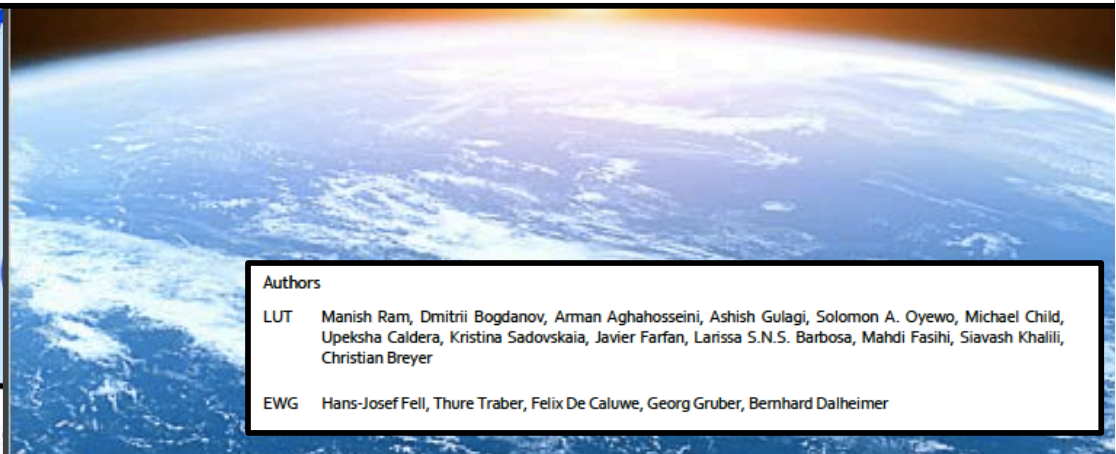
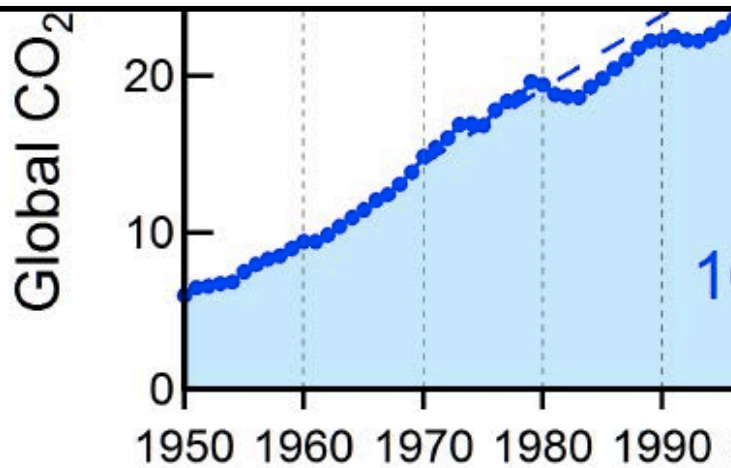
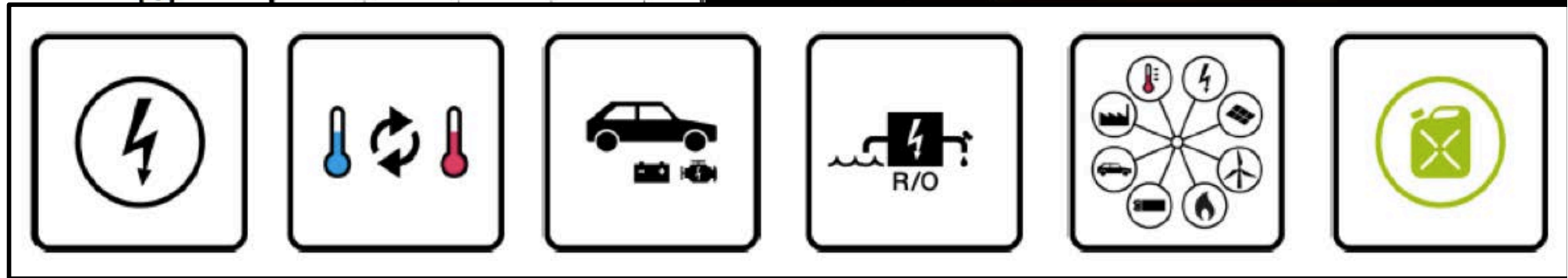
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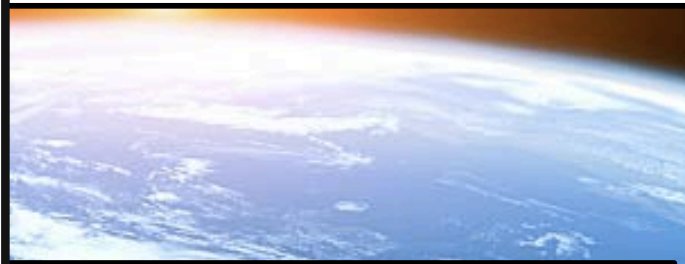
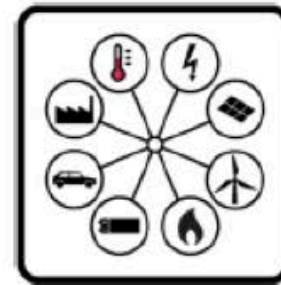
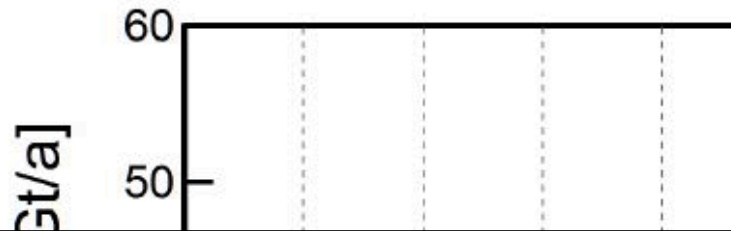
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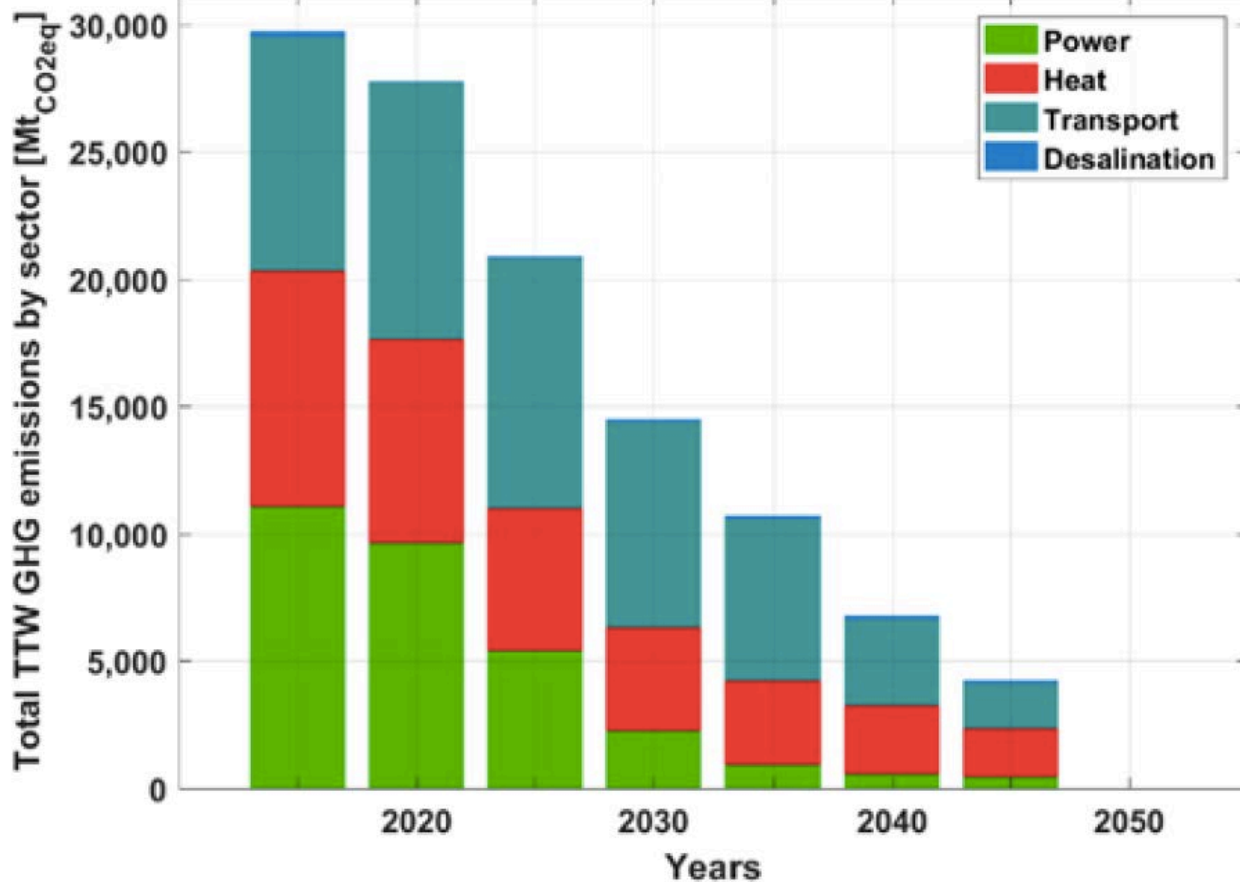
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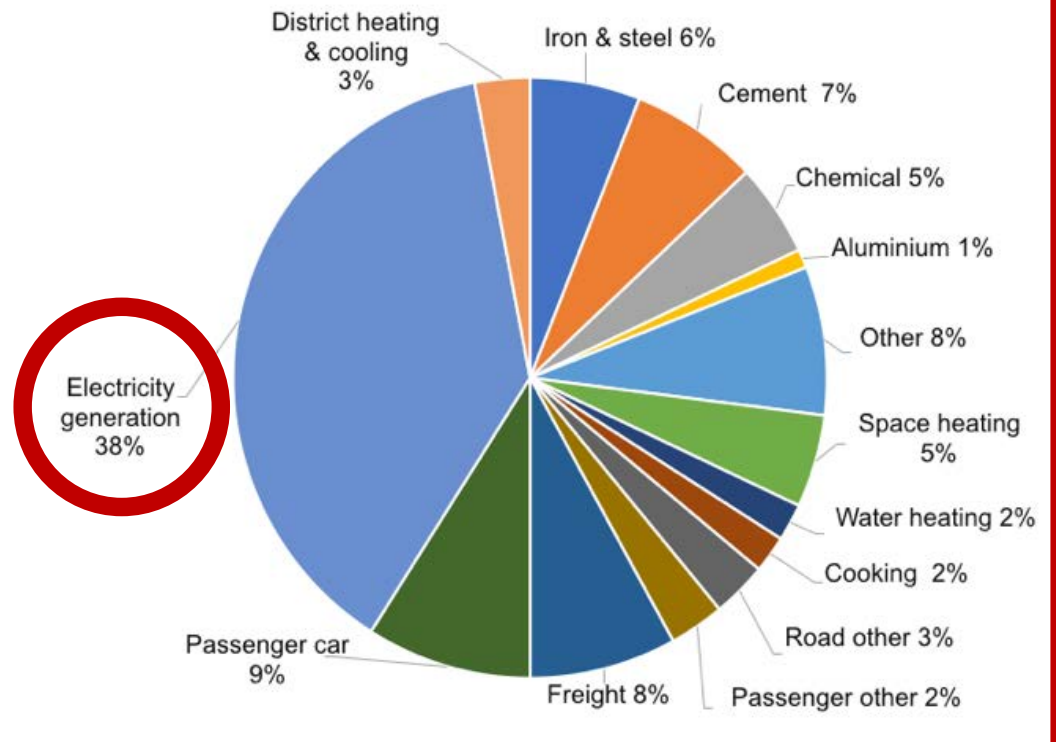
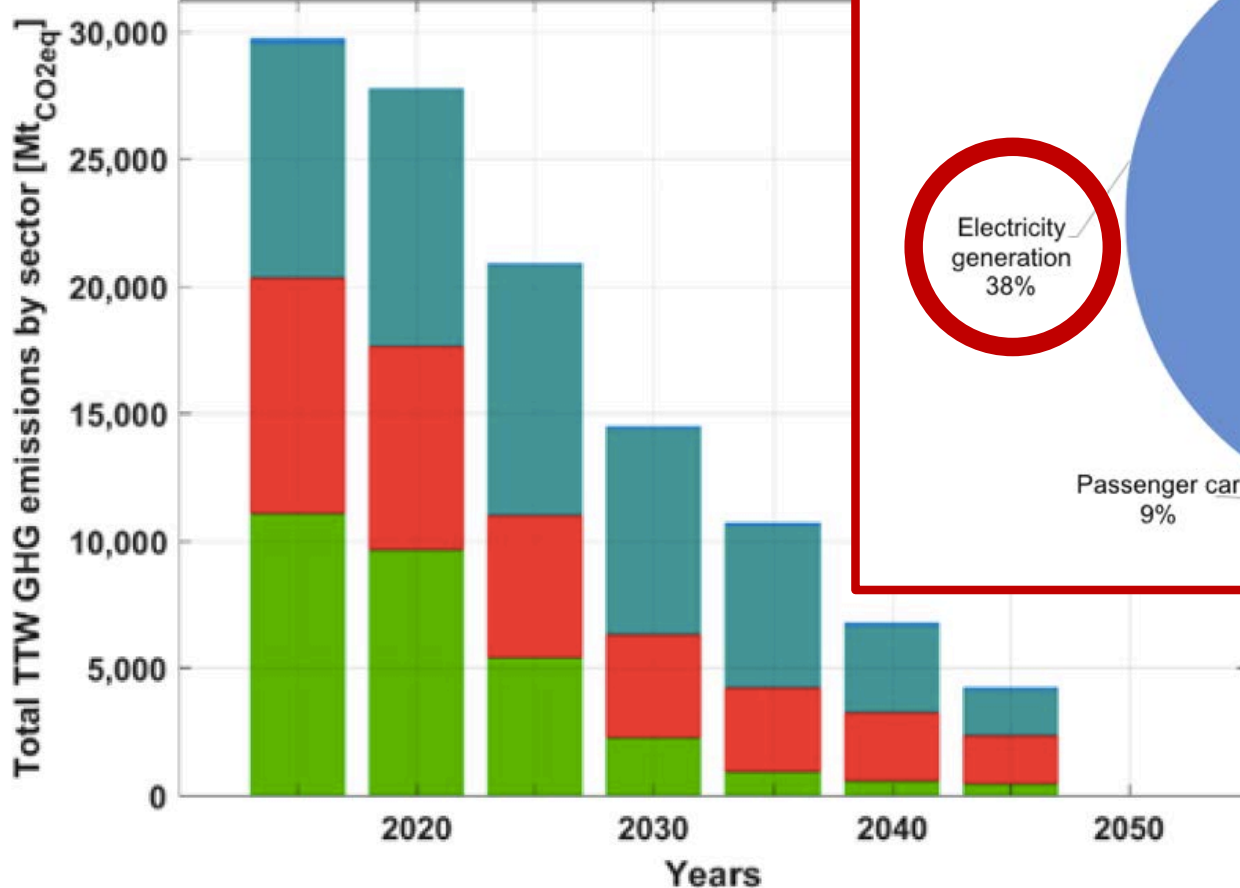
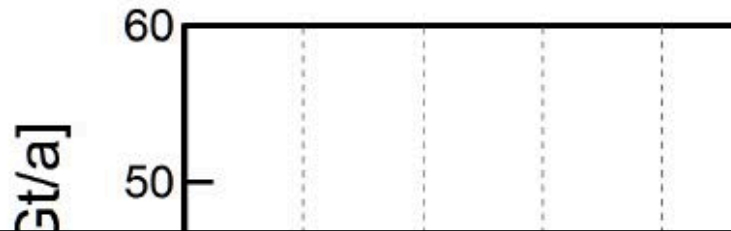
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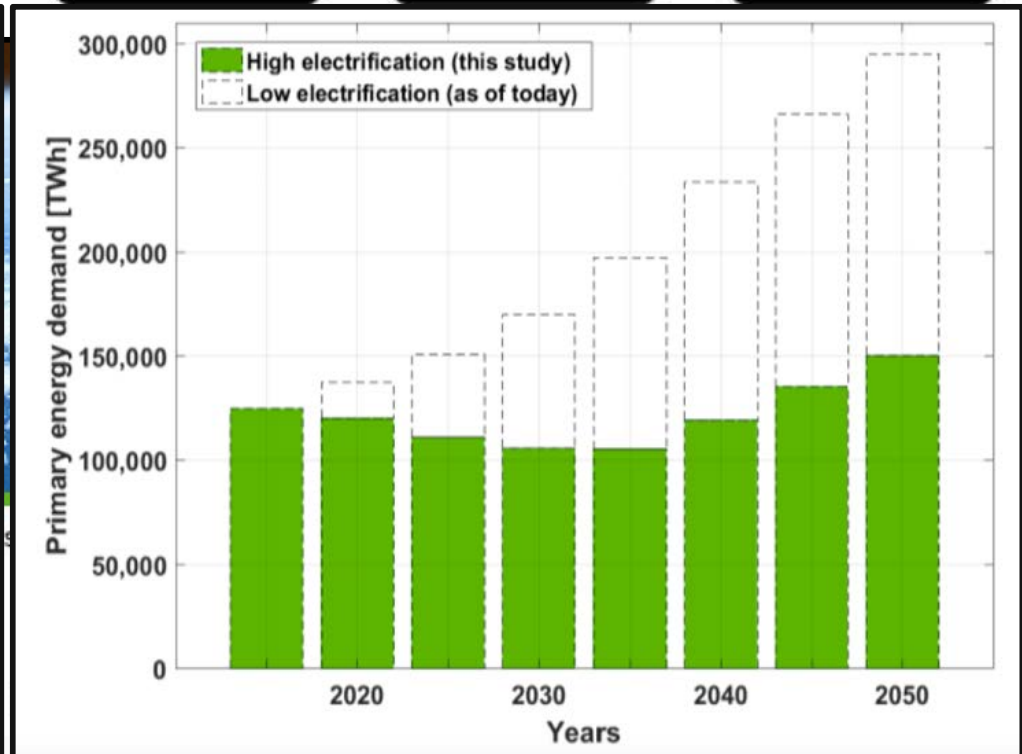
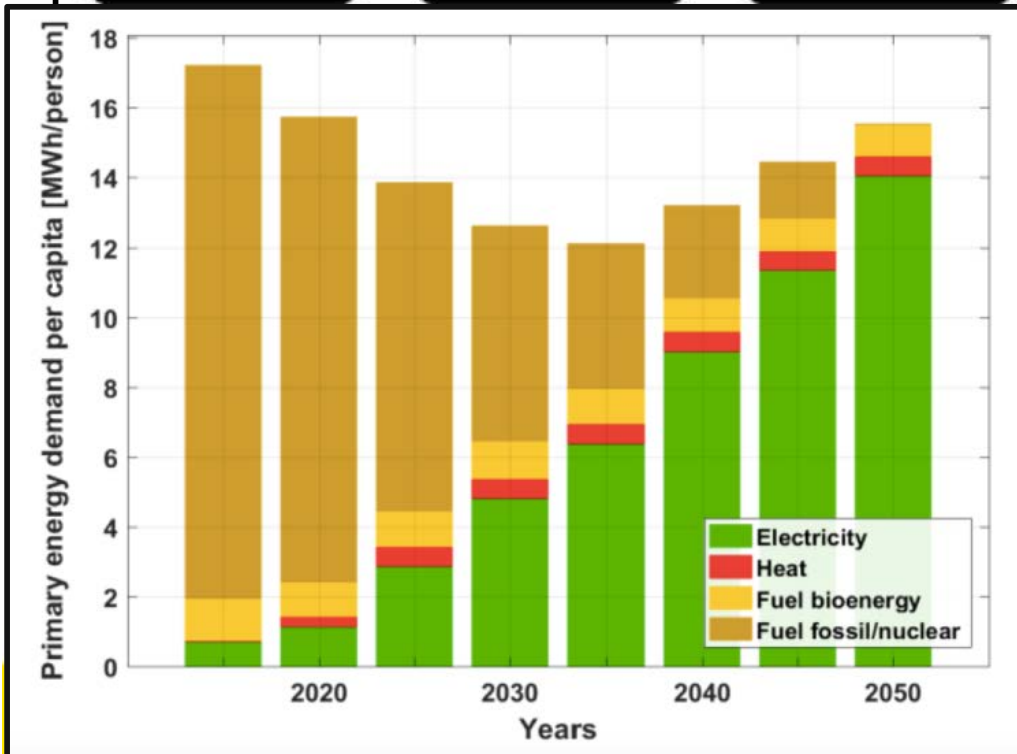
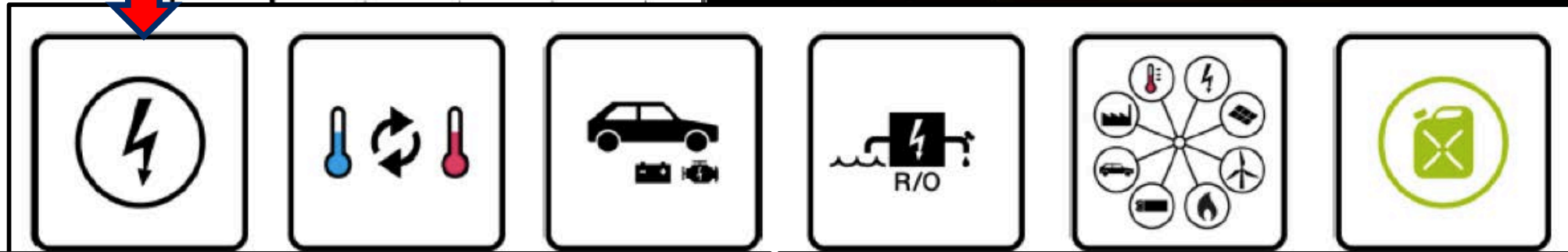
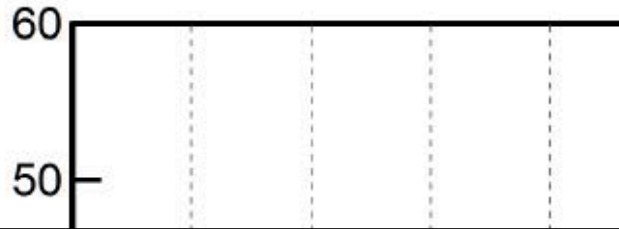
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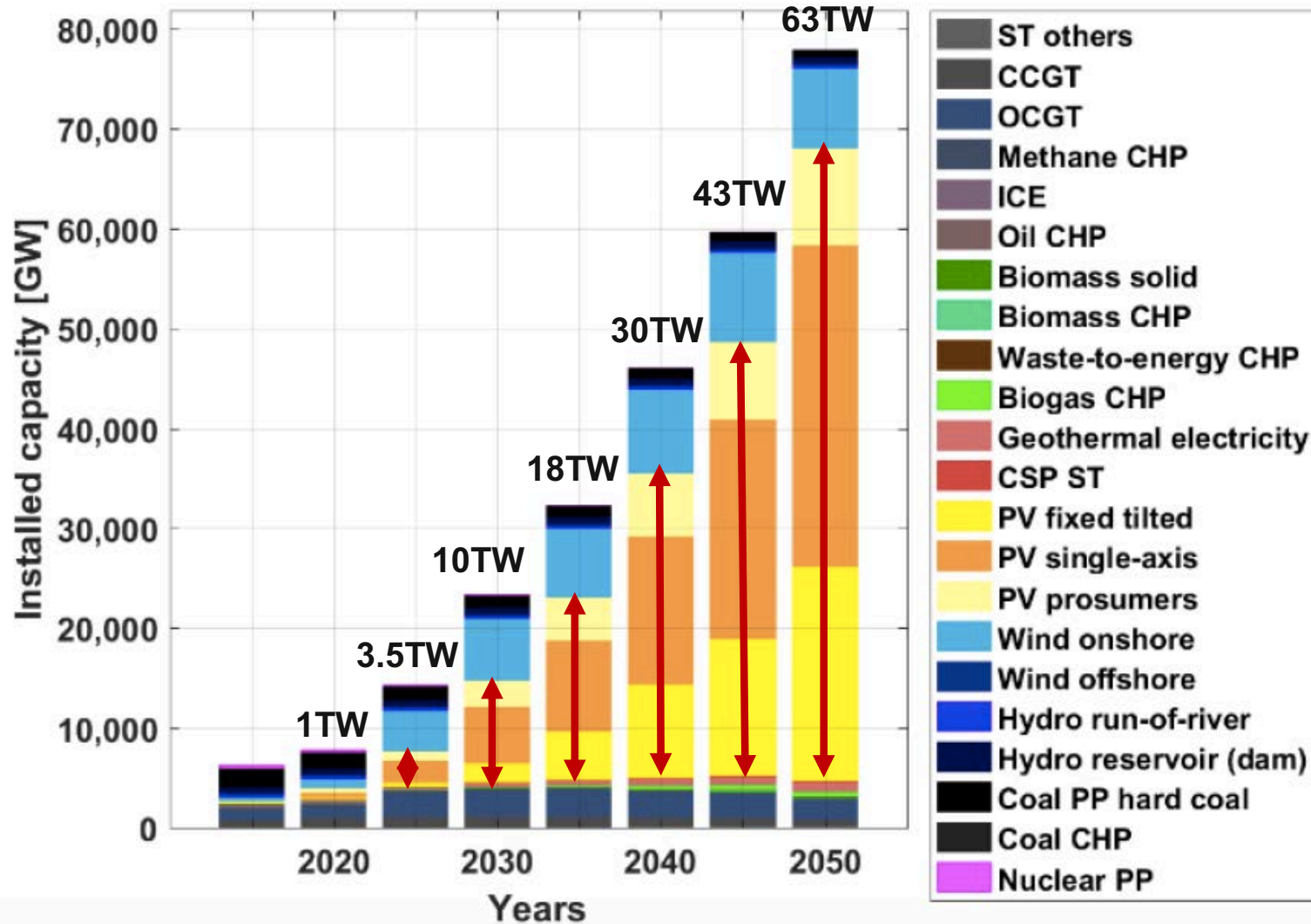
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in Sectors



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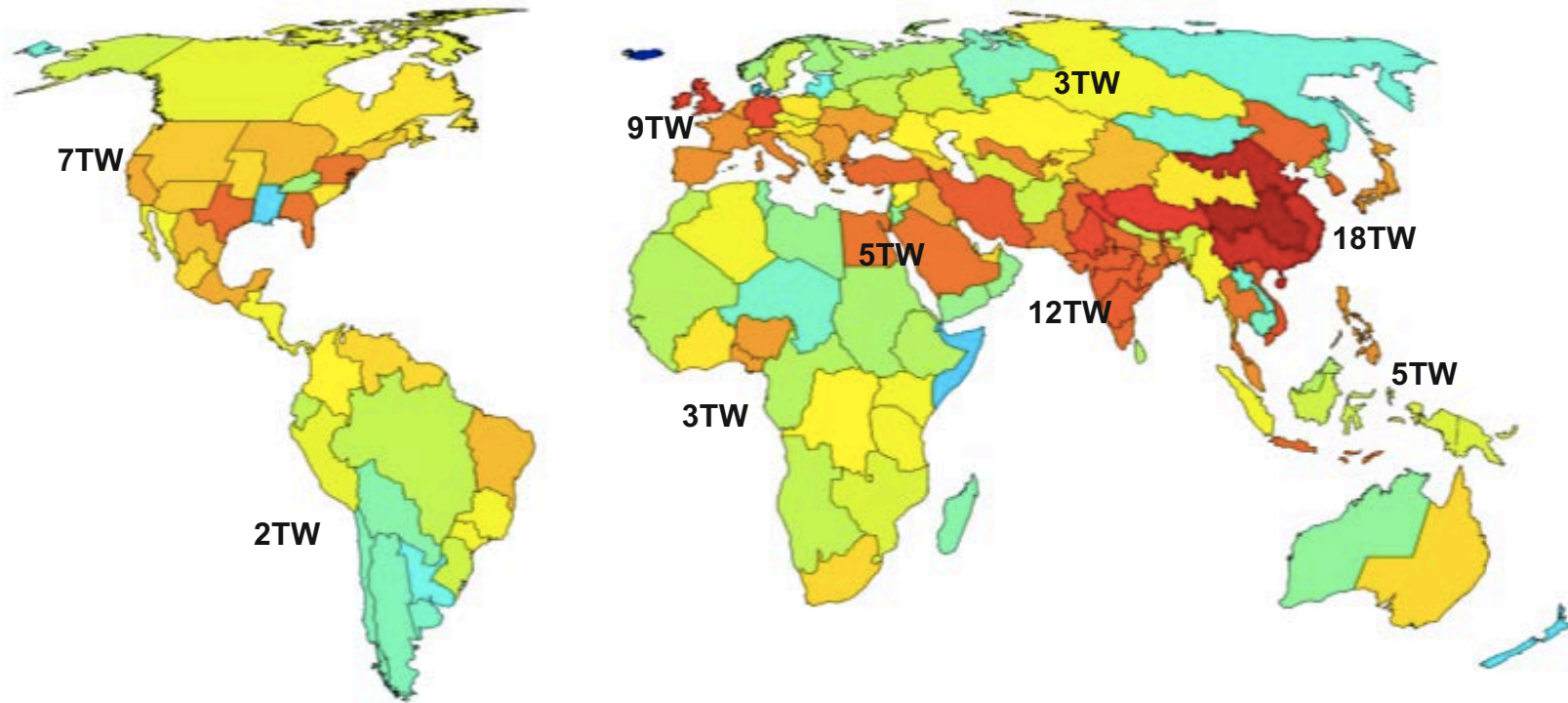


80.000

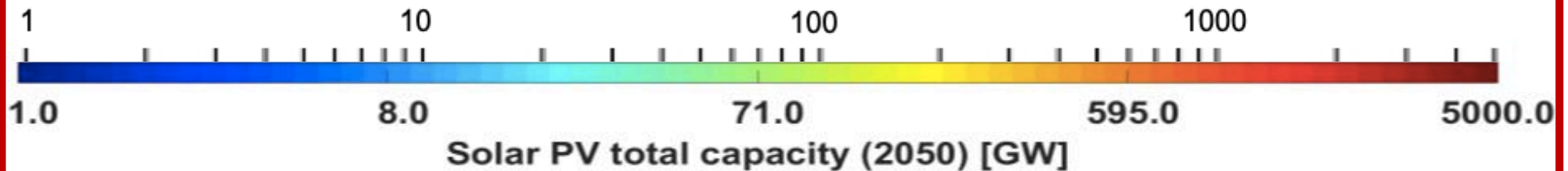
63TW

ST others

in Sectors



total for regions: 63380 GW

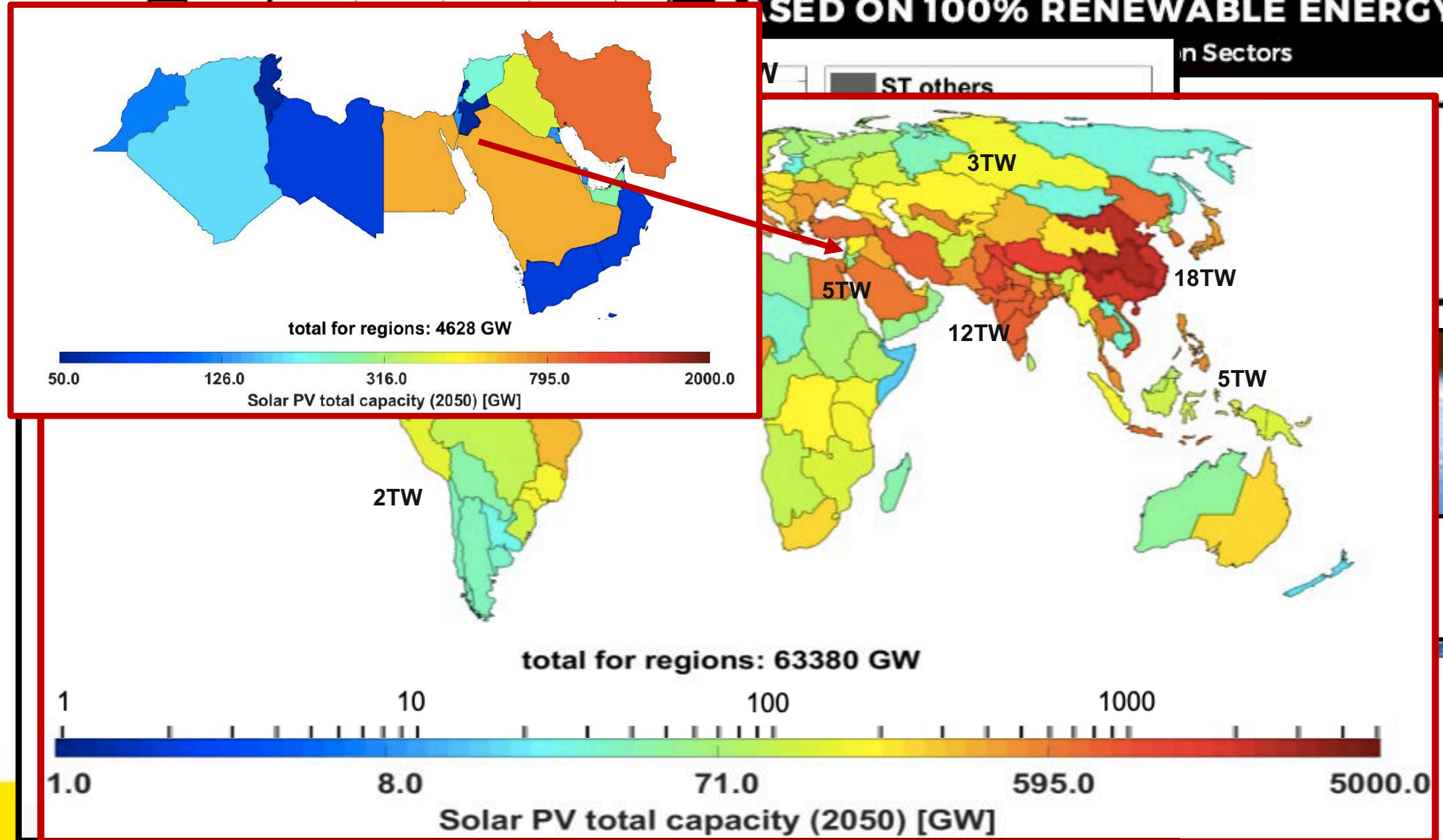


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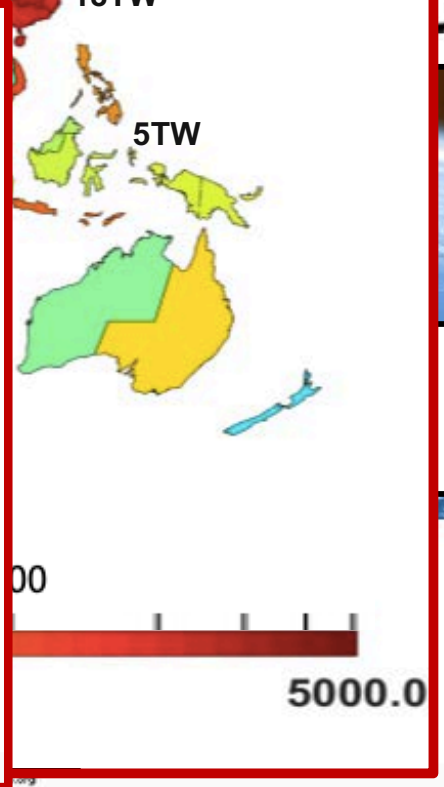
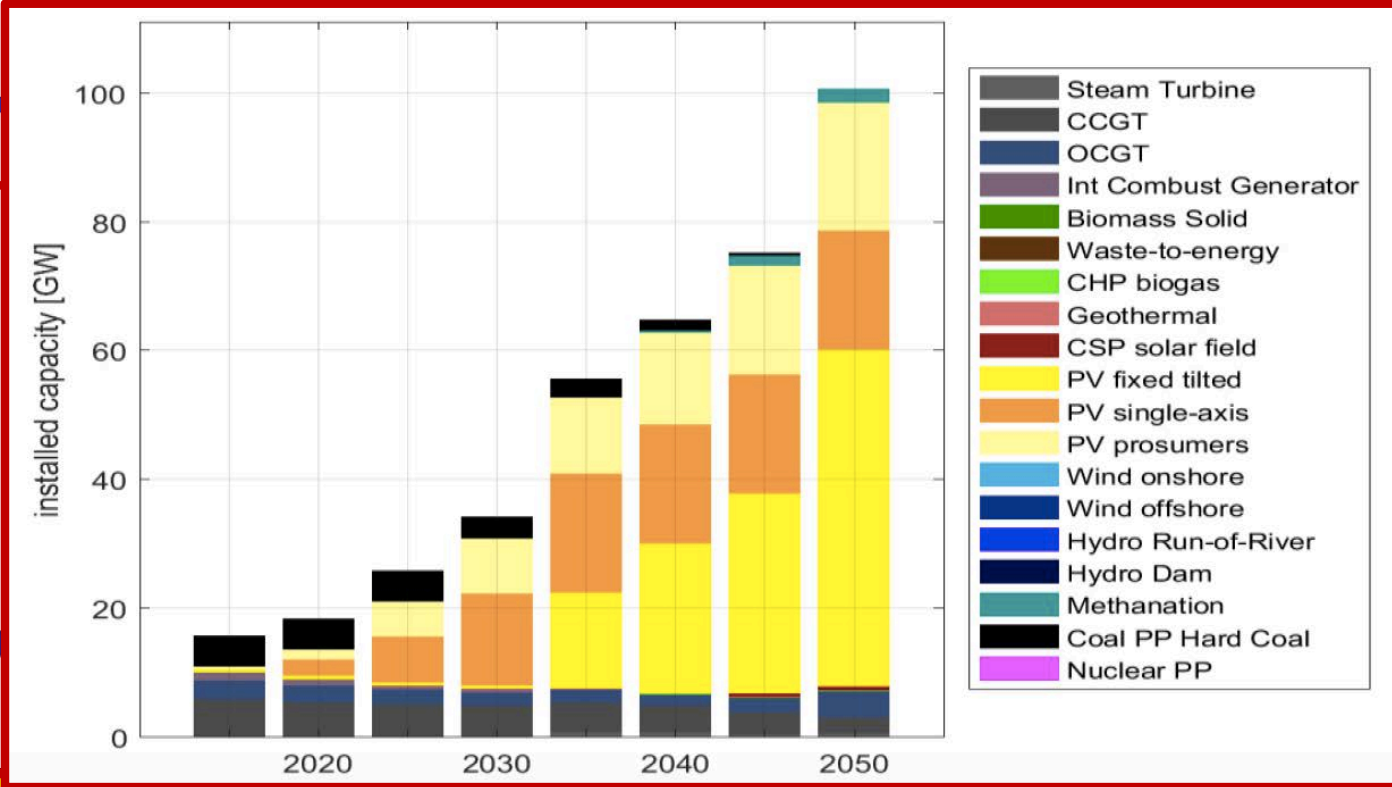
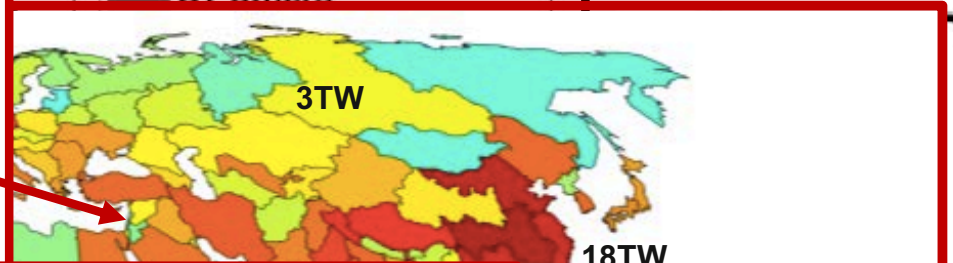
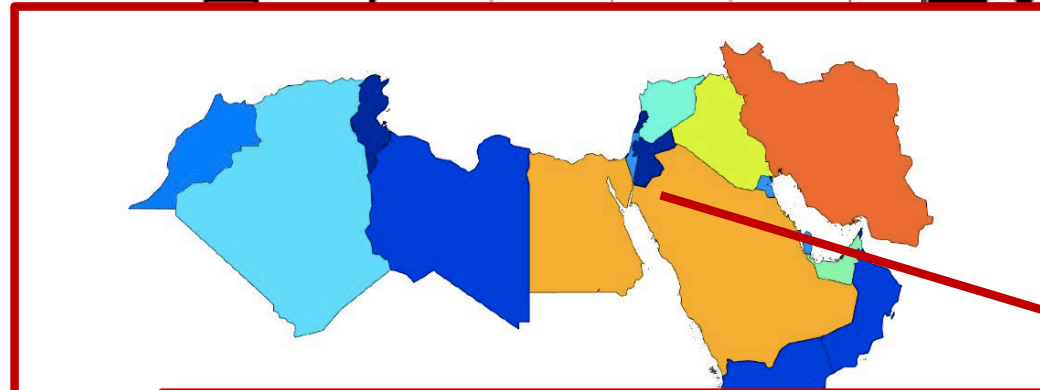
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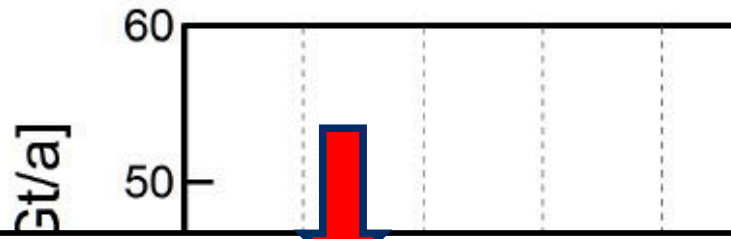
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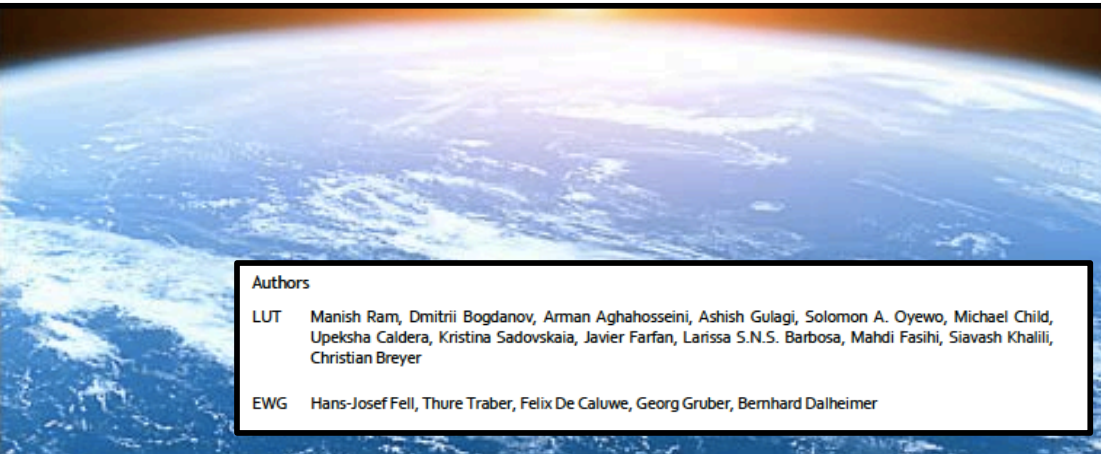
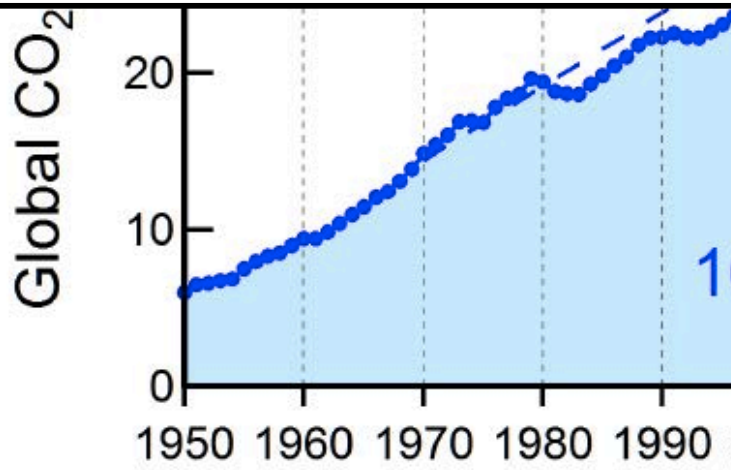
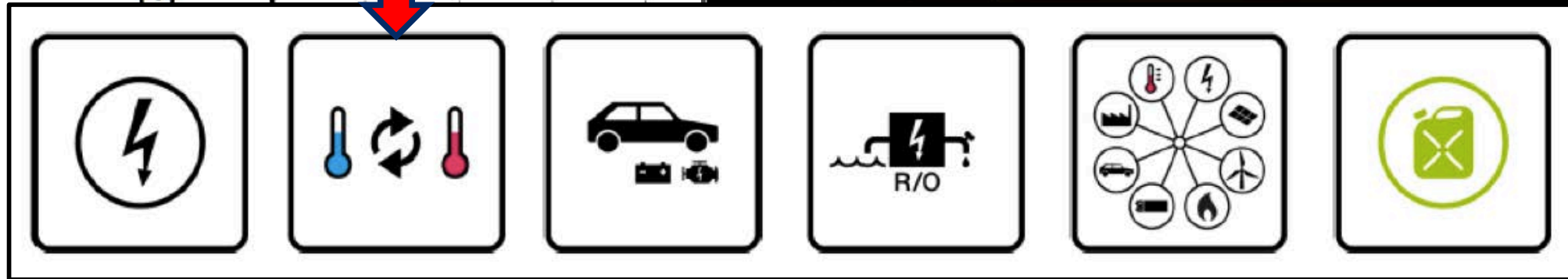
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GLOBAL ENERGY SYSTEM BASED ON 100% RENEWABLE ENERGY

Power, Heat, Transport and Desalination Sectors



Authors

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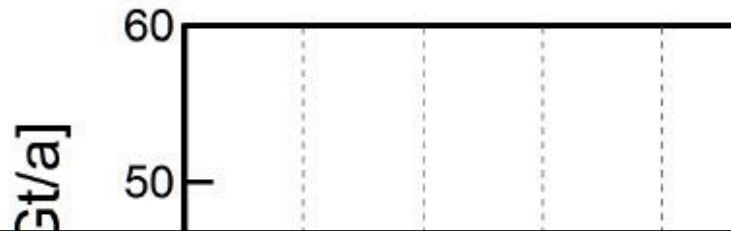


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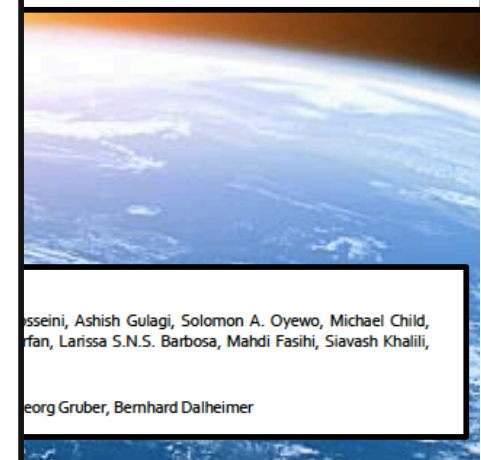
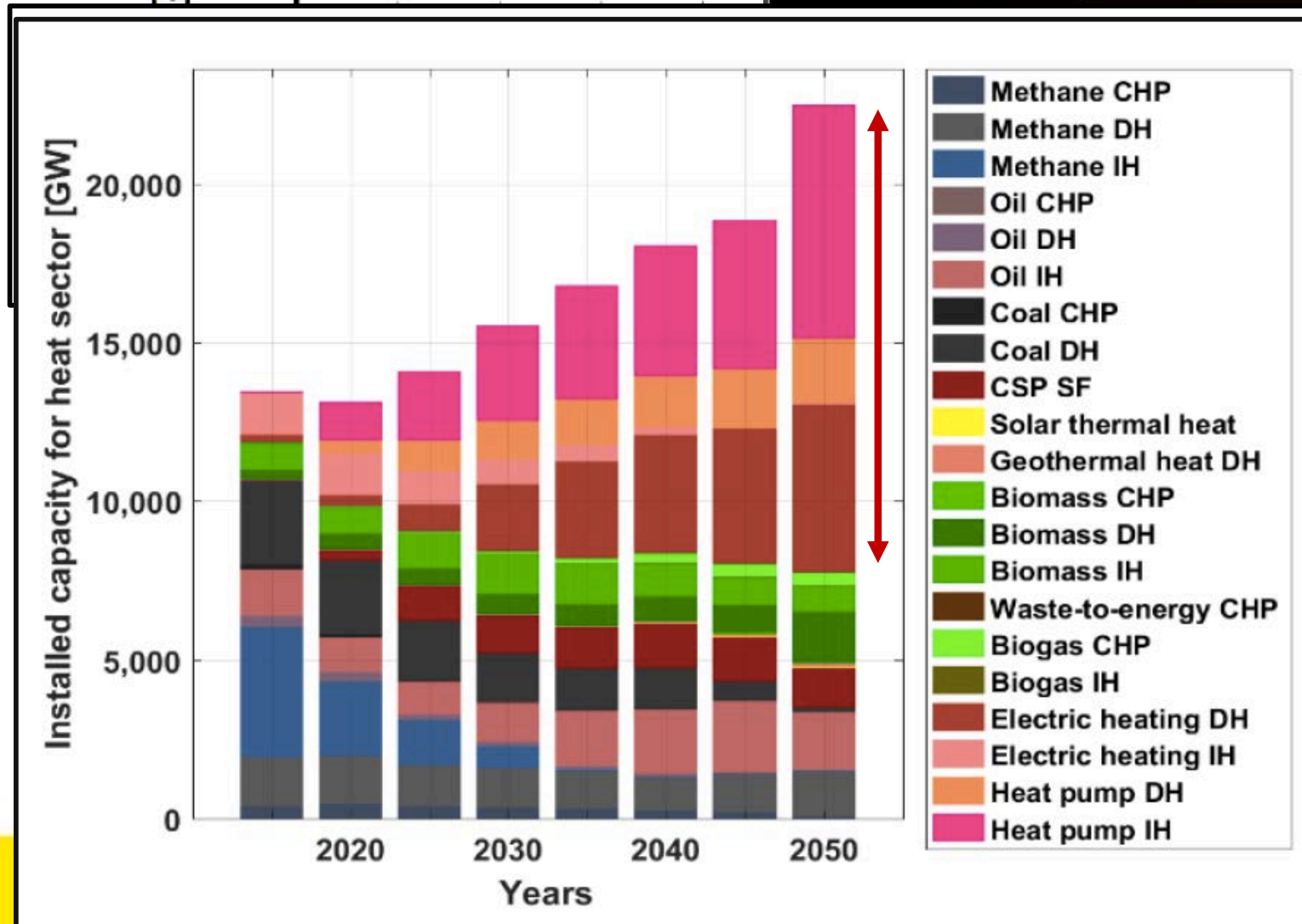
3. Solar gets CO2 under control

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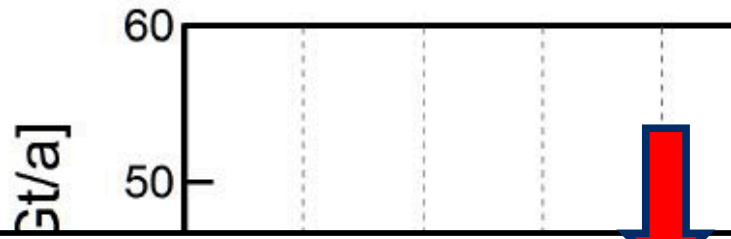
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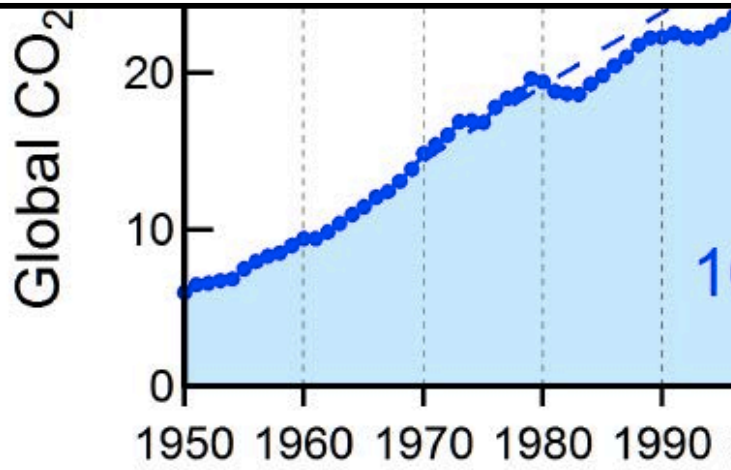
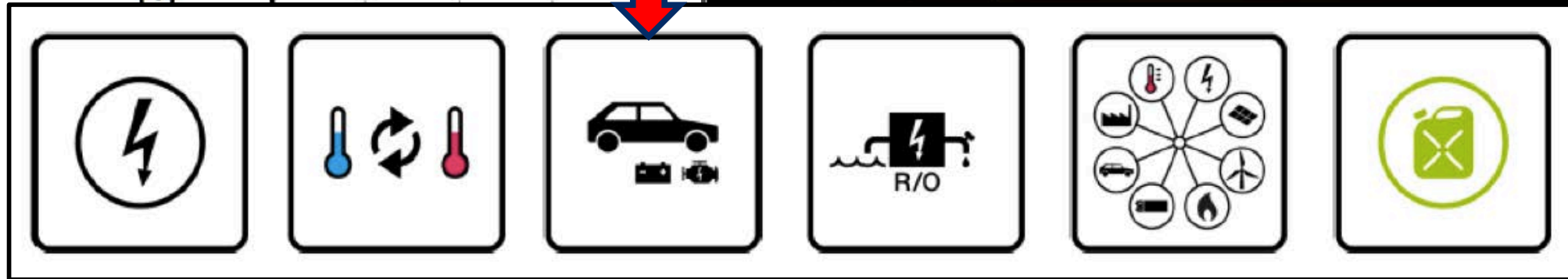
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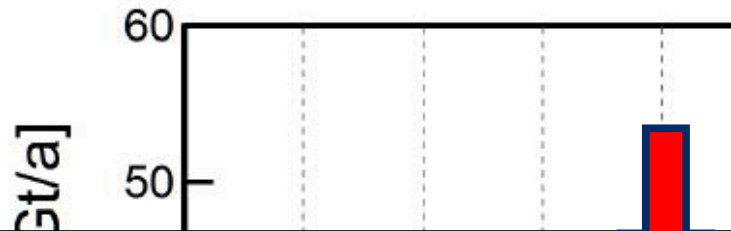
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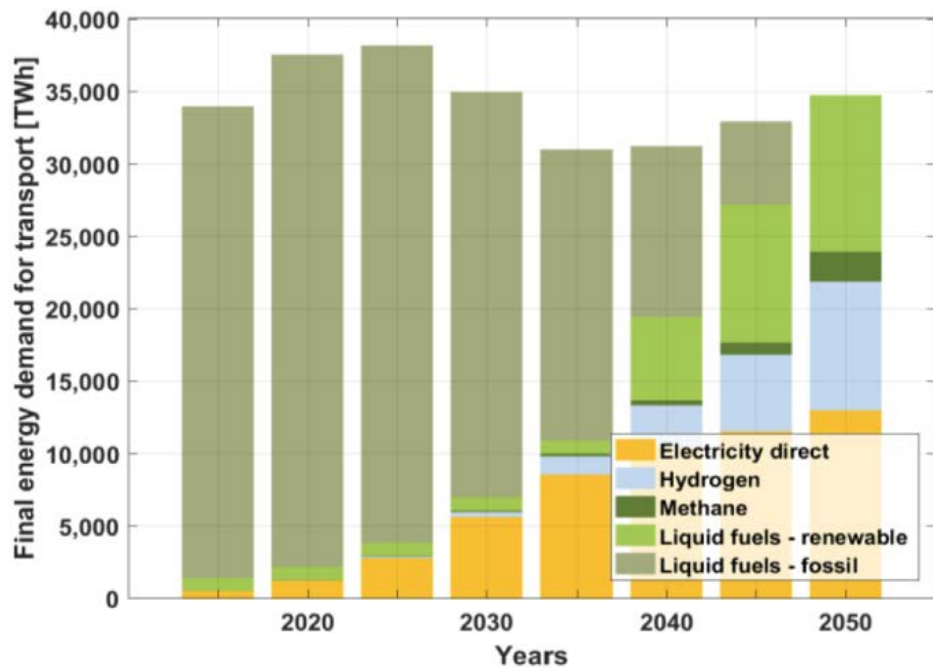
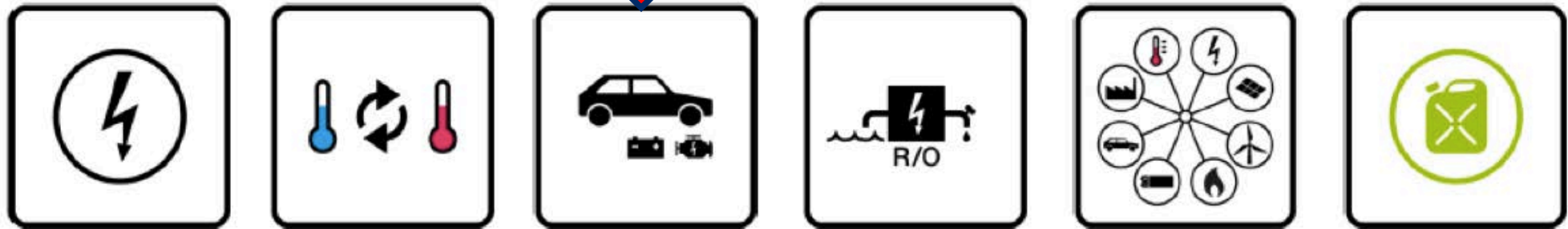
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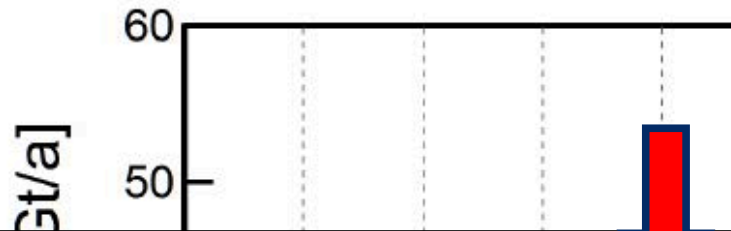
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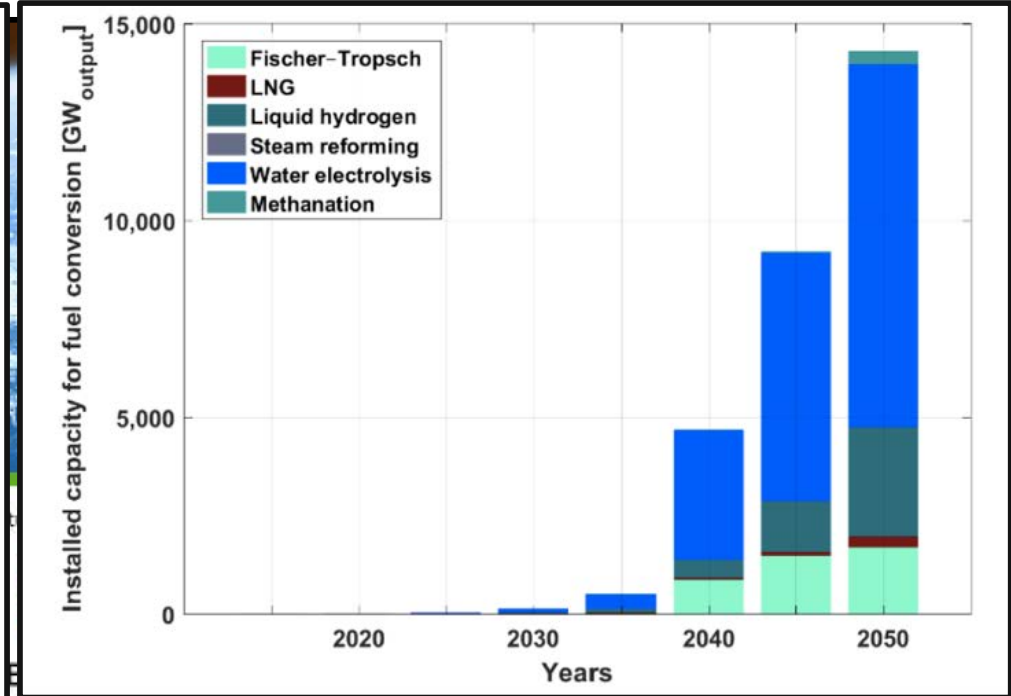
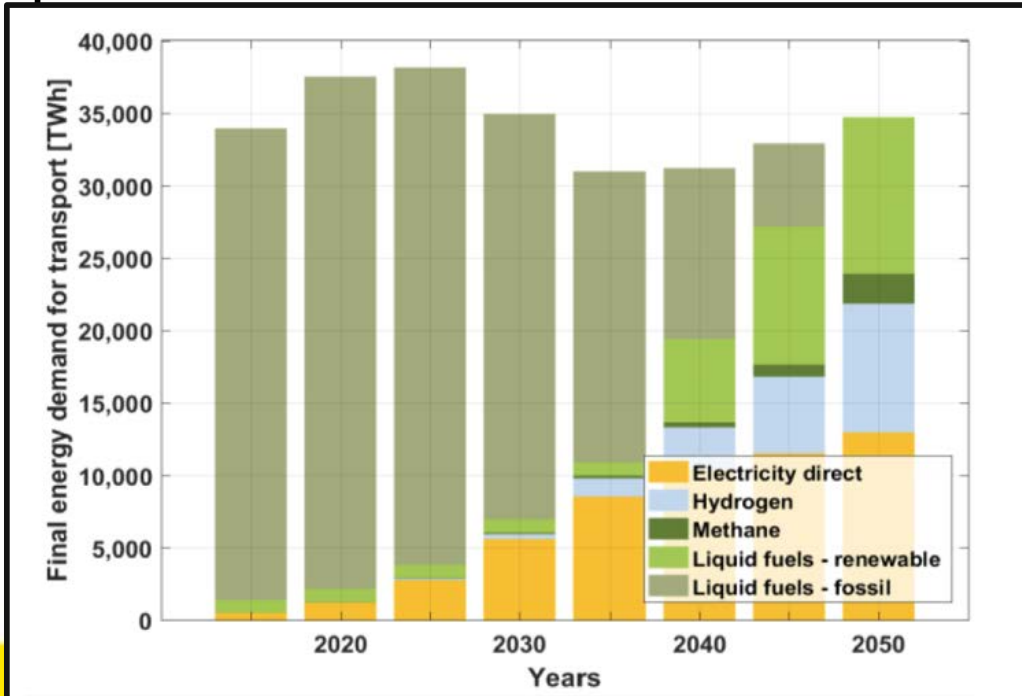
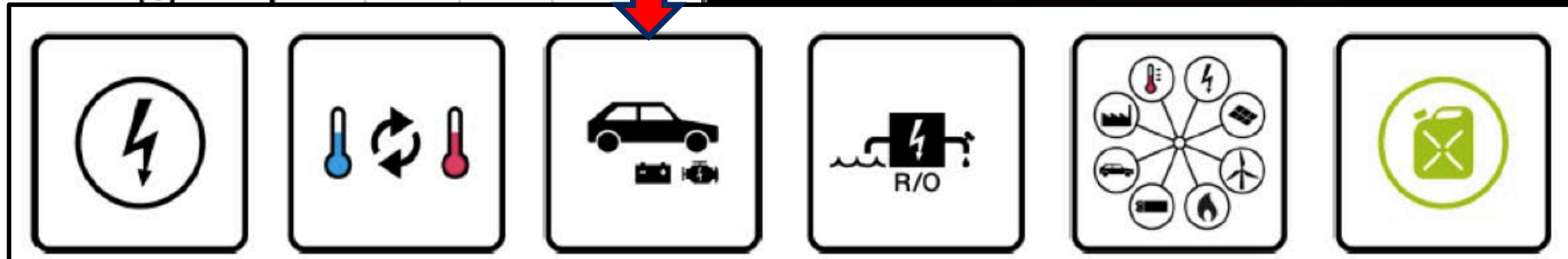
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Summary

1. Recent shake-up PV technology
2. Si-tandems evolve to thin-film tandems
3. Market continues to grow rapidly
4. TW era approaches

