



ARENA



“Solar Photovoltaics: Power Source for the Future”

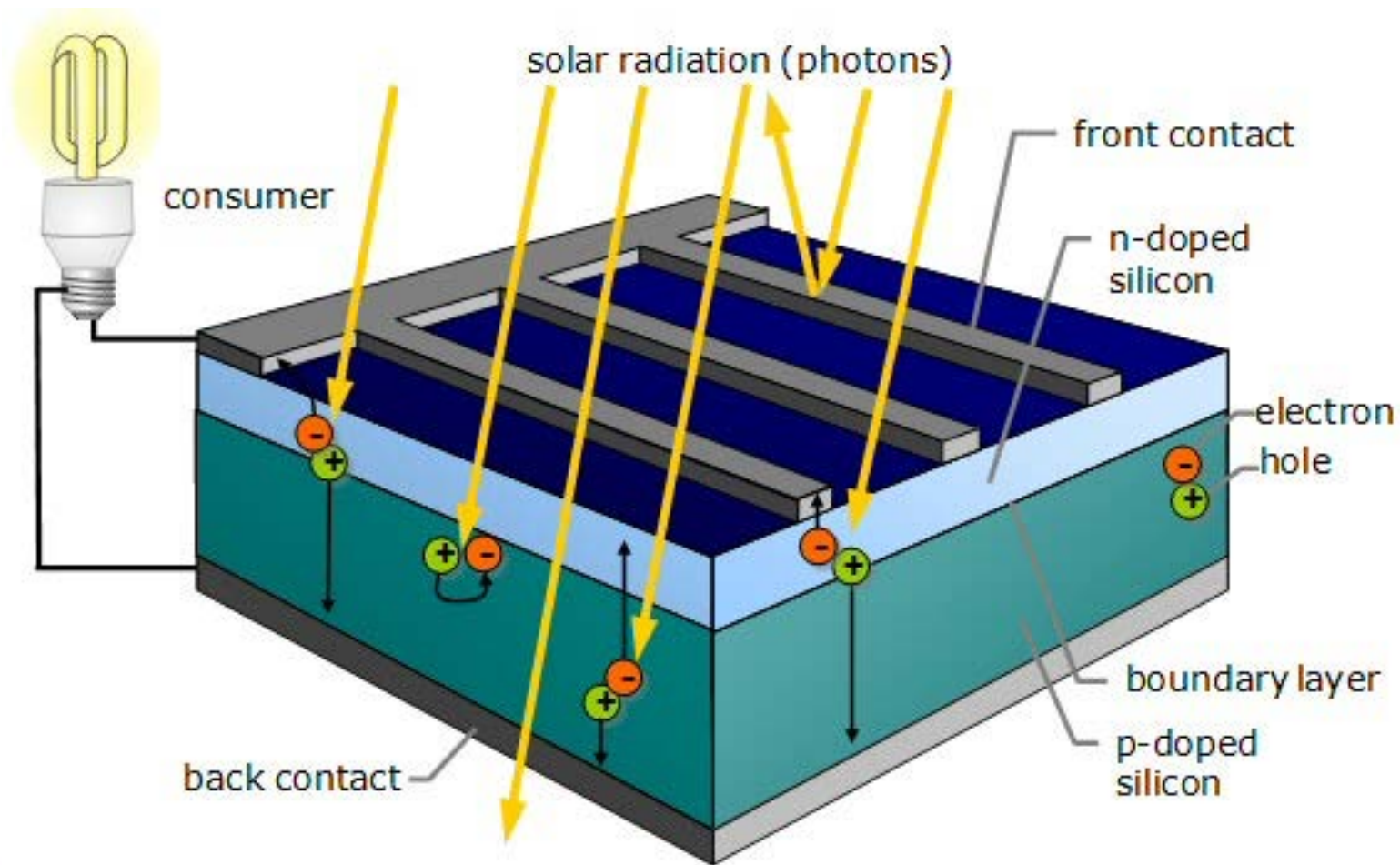
Martin Green, UNSW Sydney, Australia



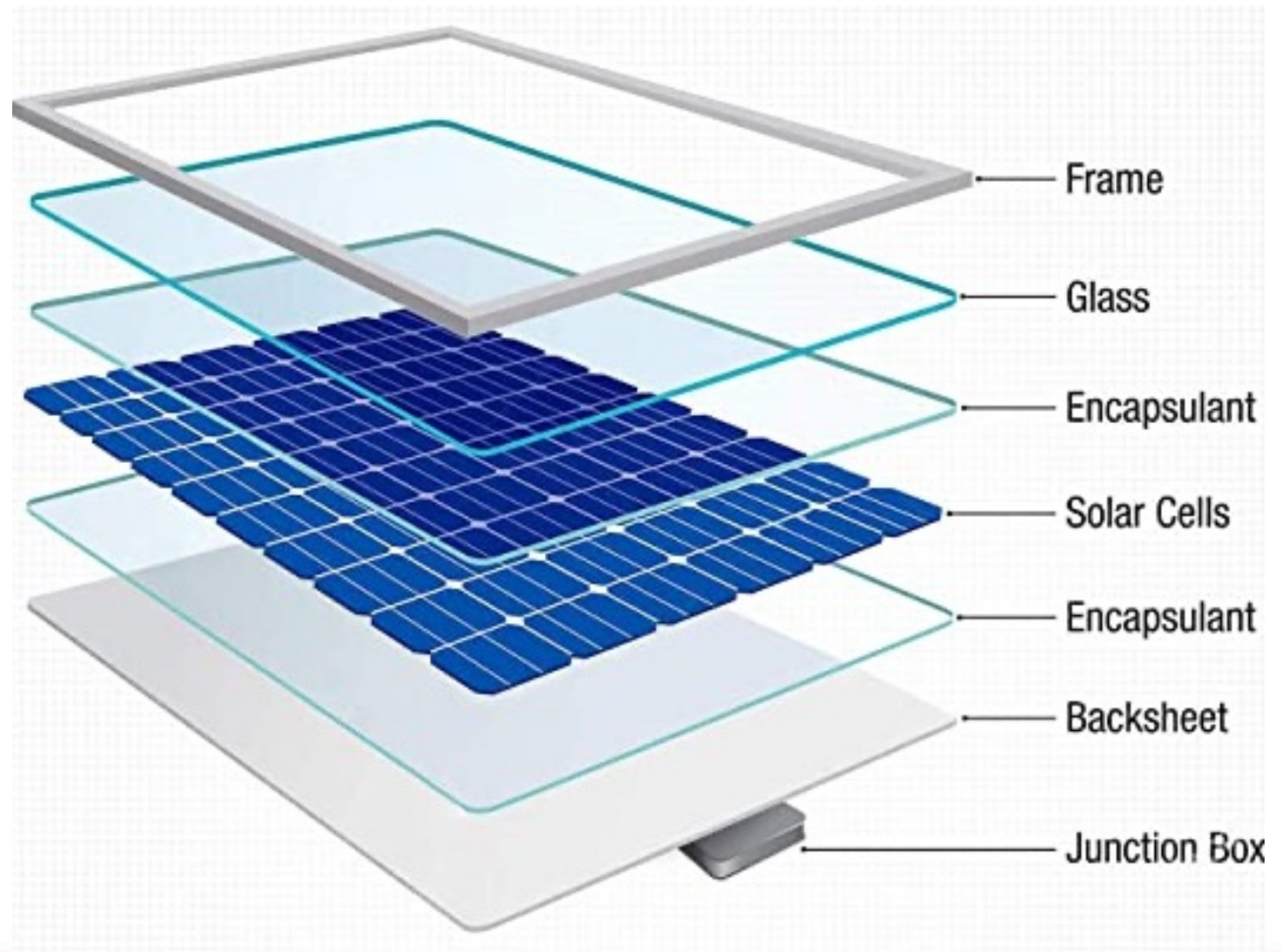
Part 1: Introduction



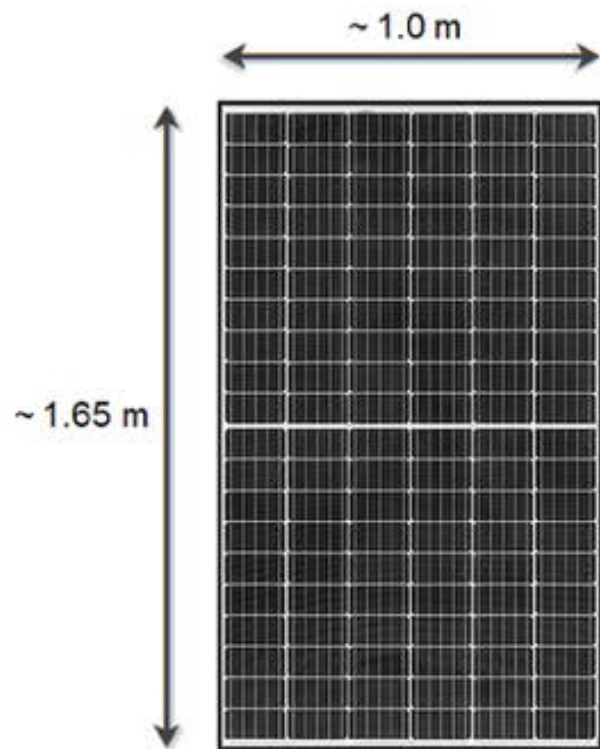
Solar cell



Solar module

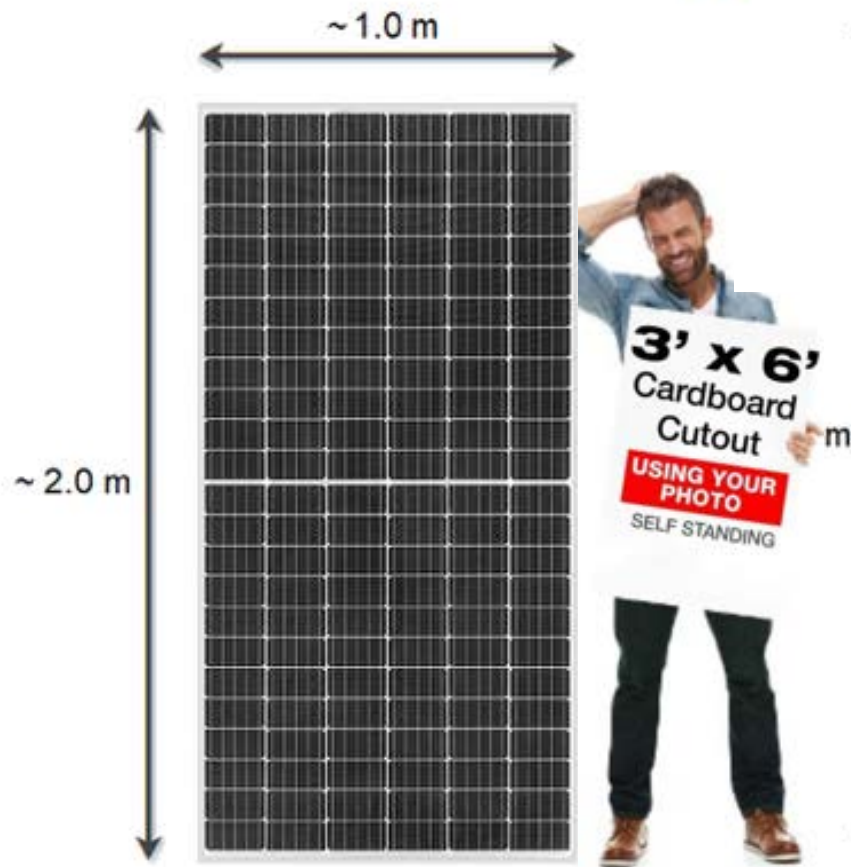


Solar Panel Size Vs Power Output



60 cells (120 HC)

300W - 380W

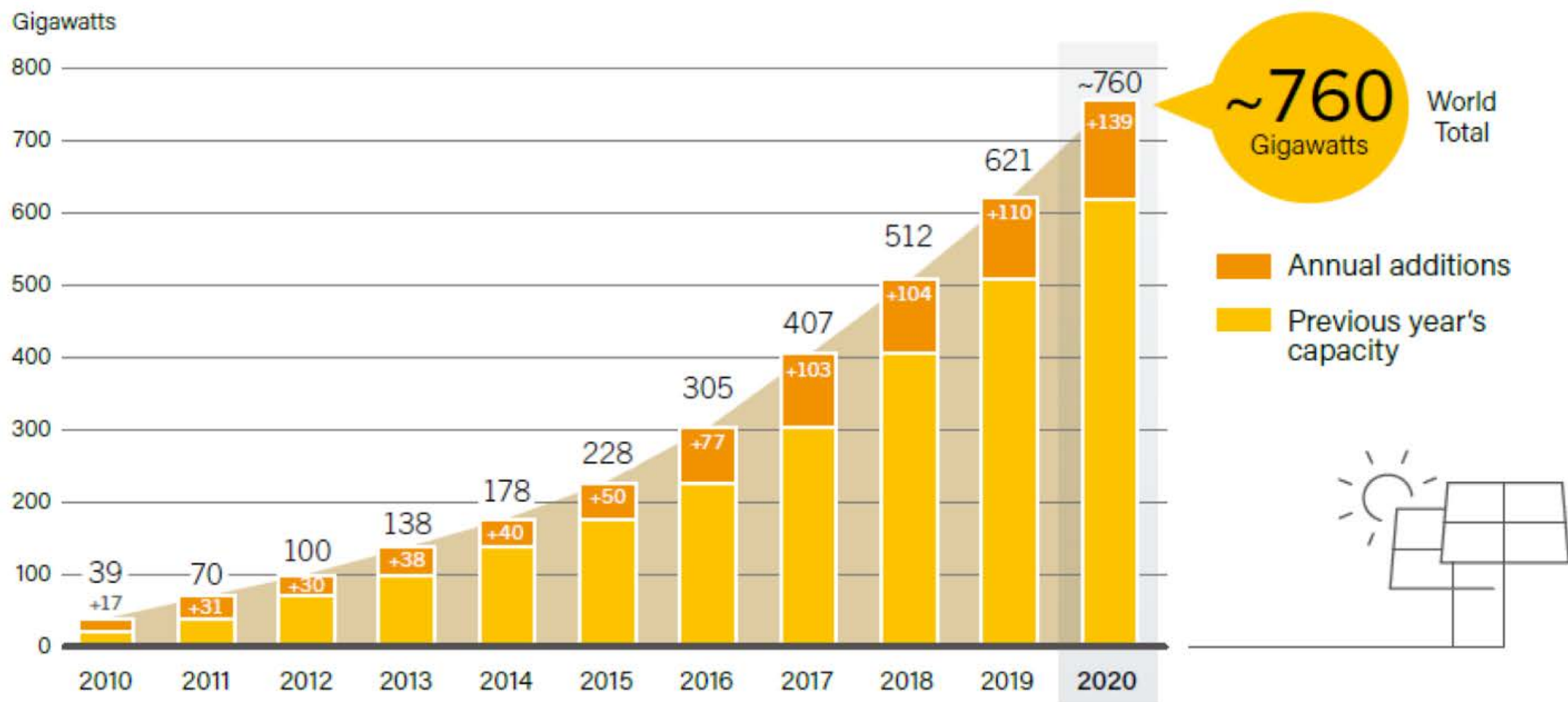


72 cells (144 HC)

350W - 450W

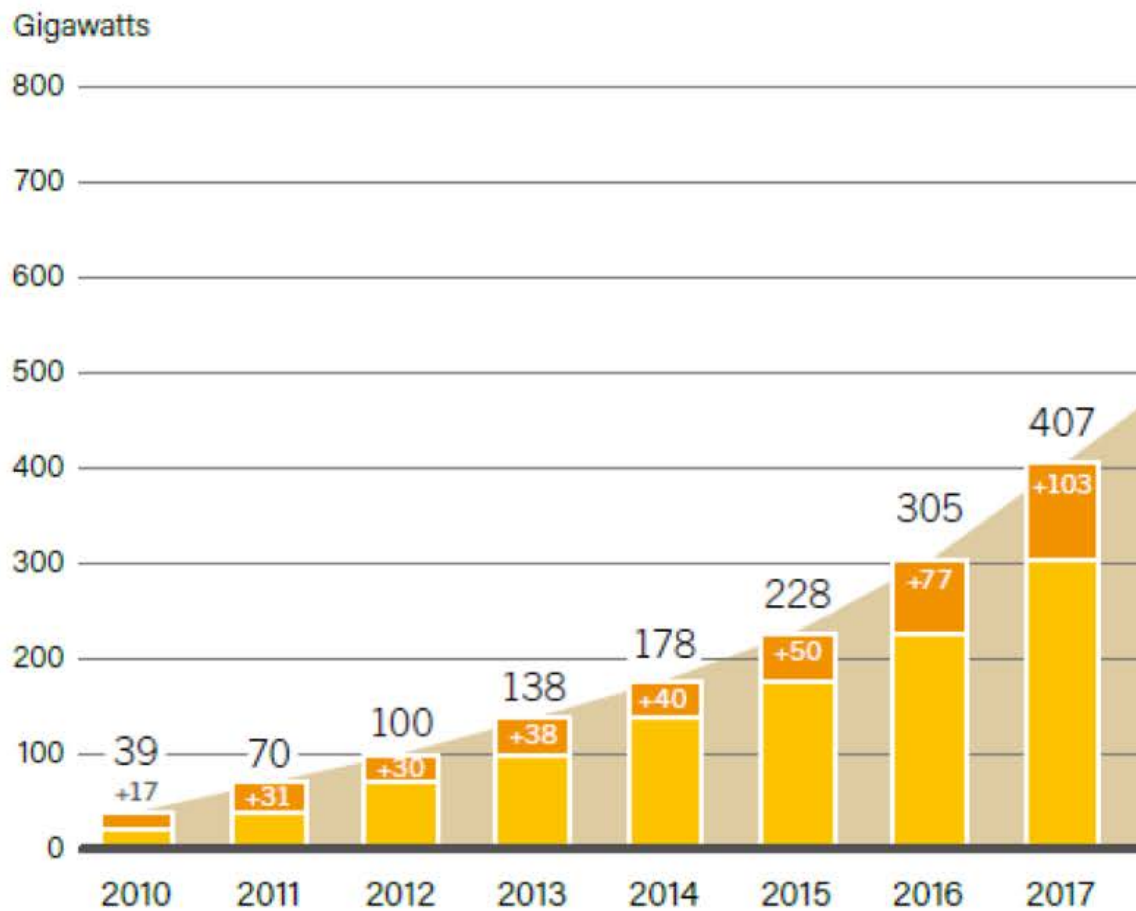


Solar PV Global Capacity and Annual Additions, 2010-2020

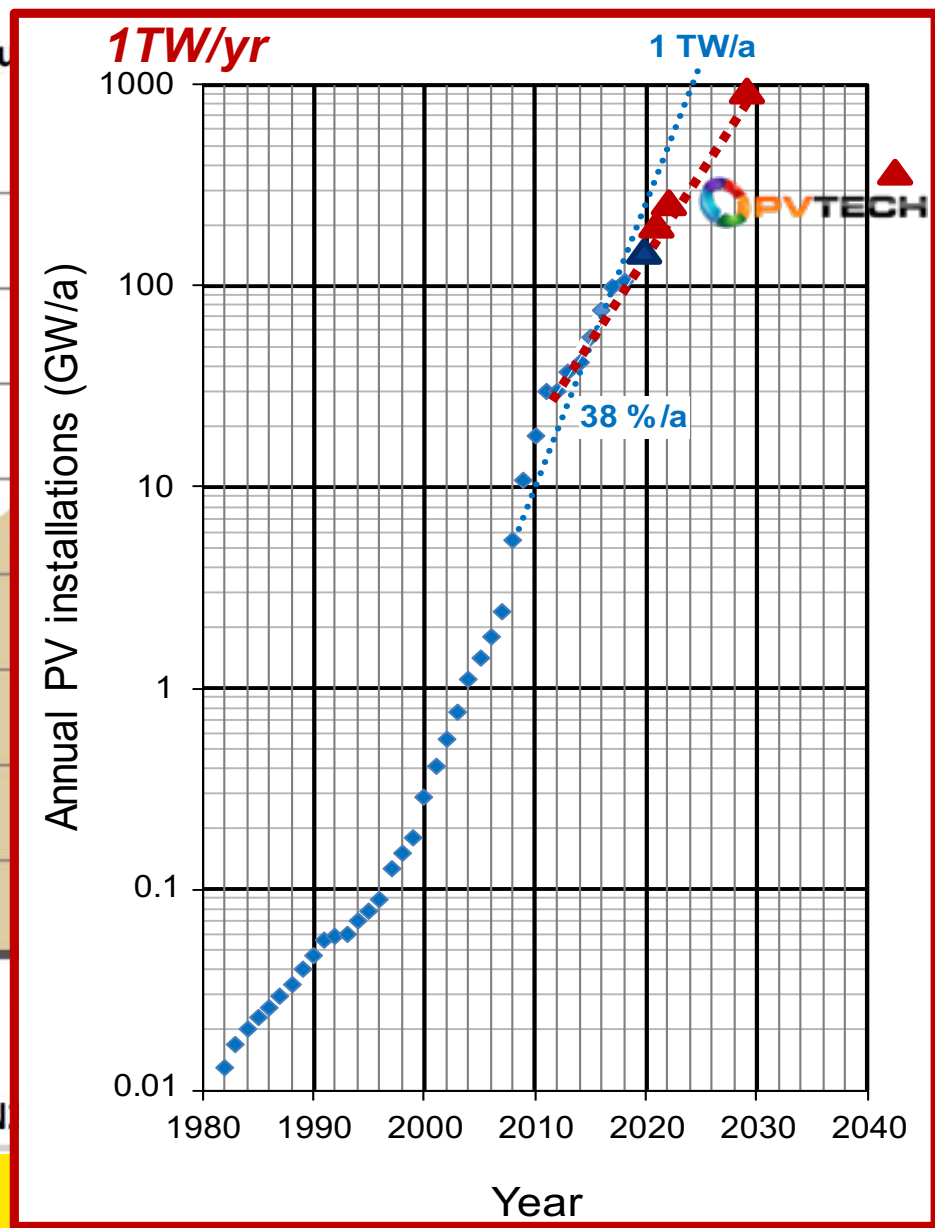


Source: REN21

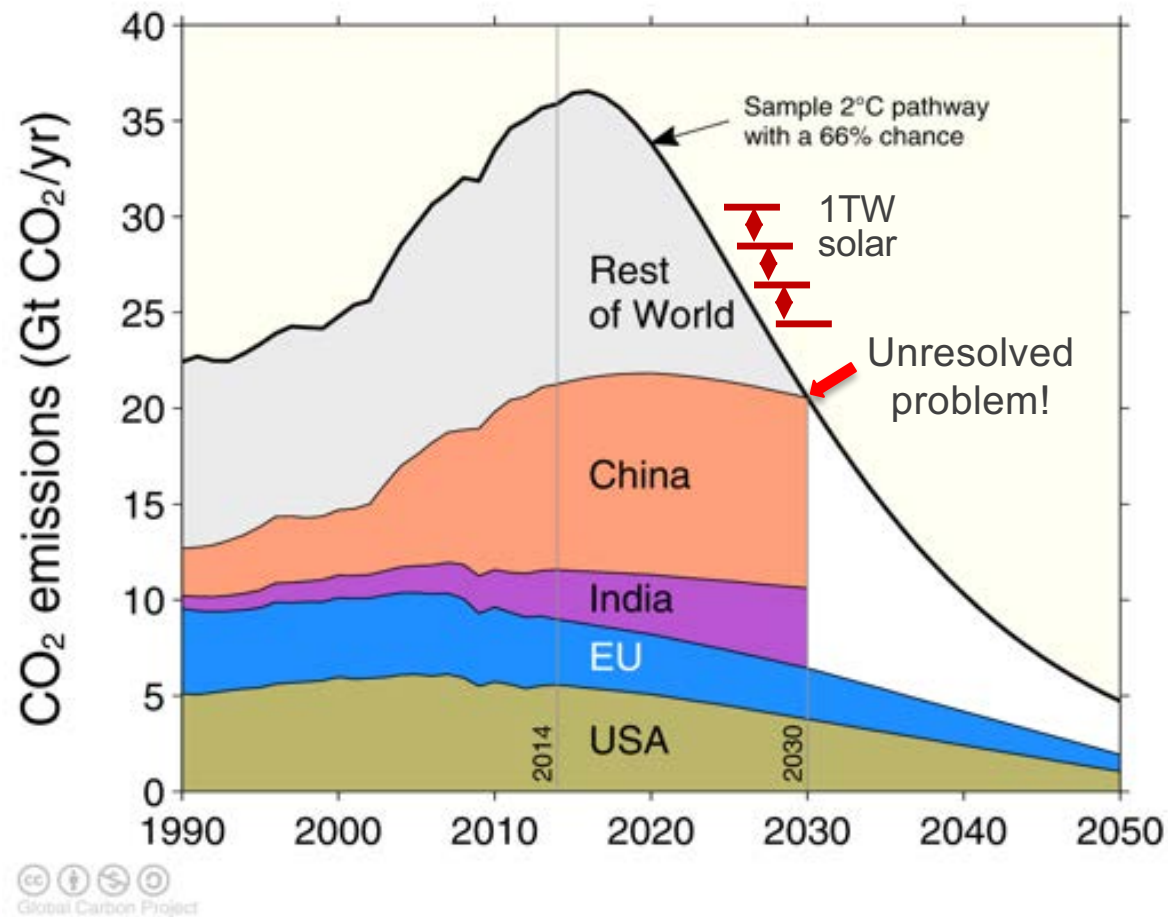
Solar PV Global Capacity and Annual



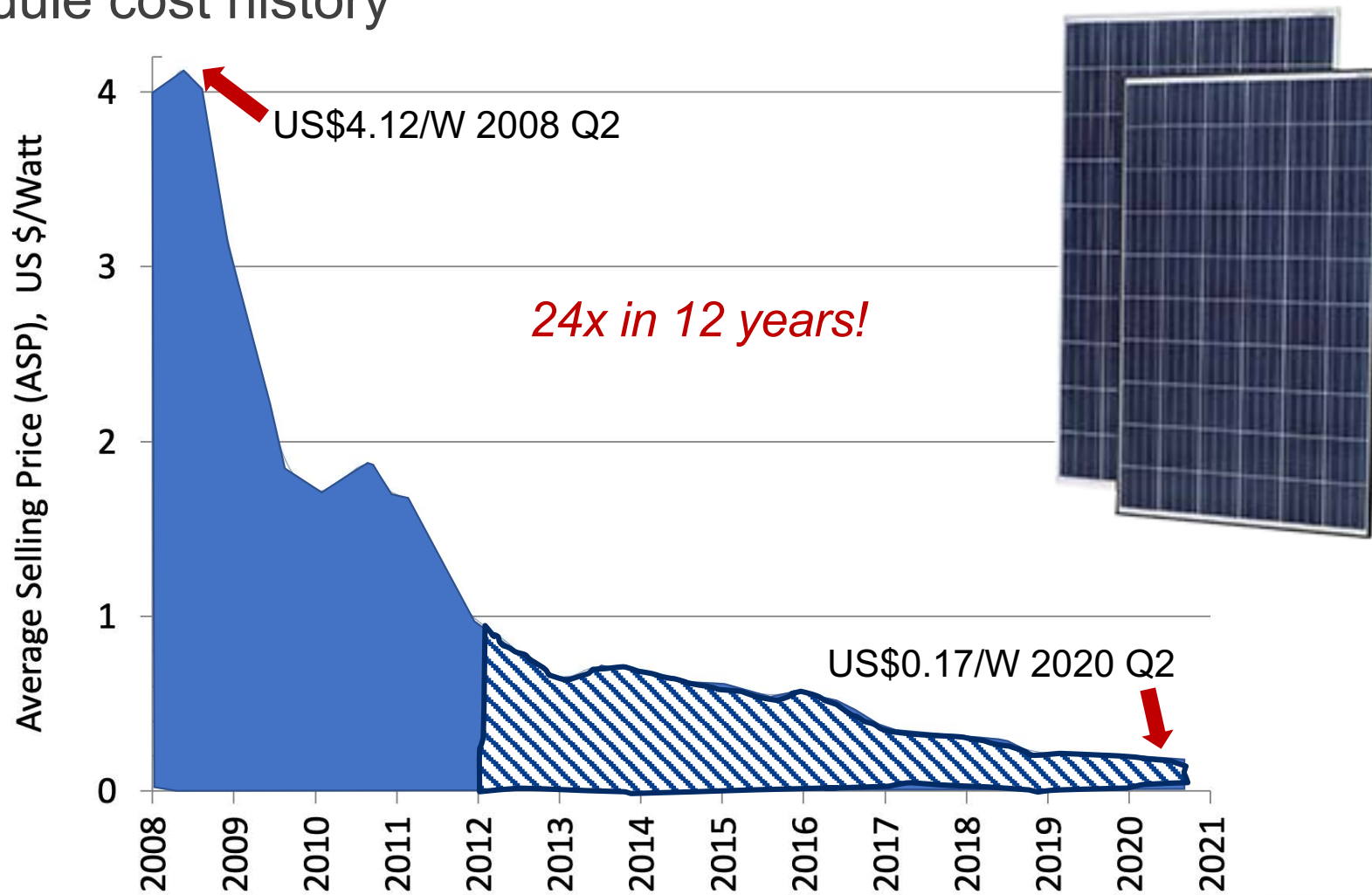
Source: REN



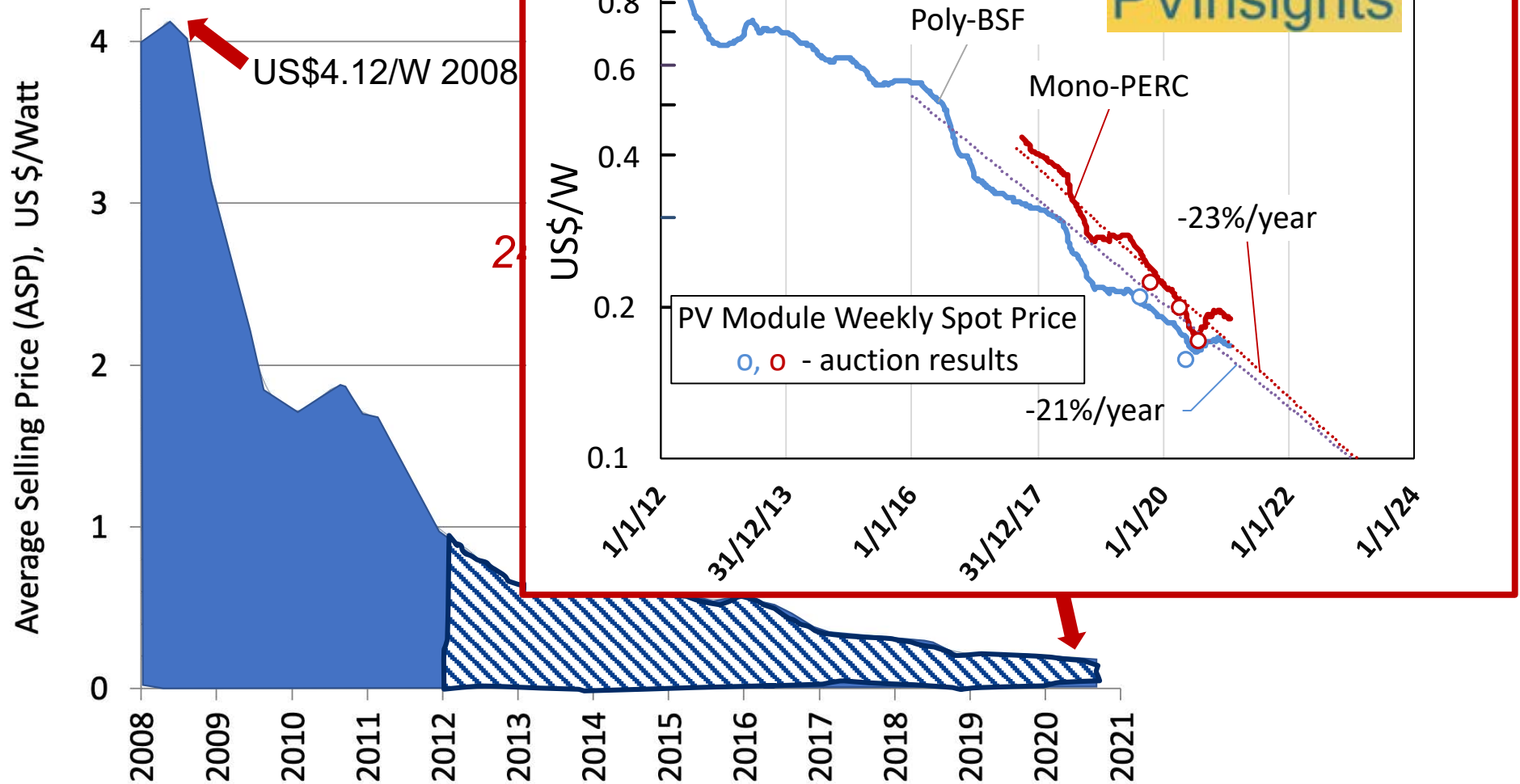
Solar to the rescue?

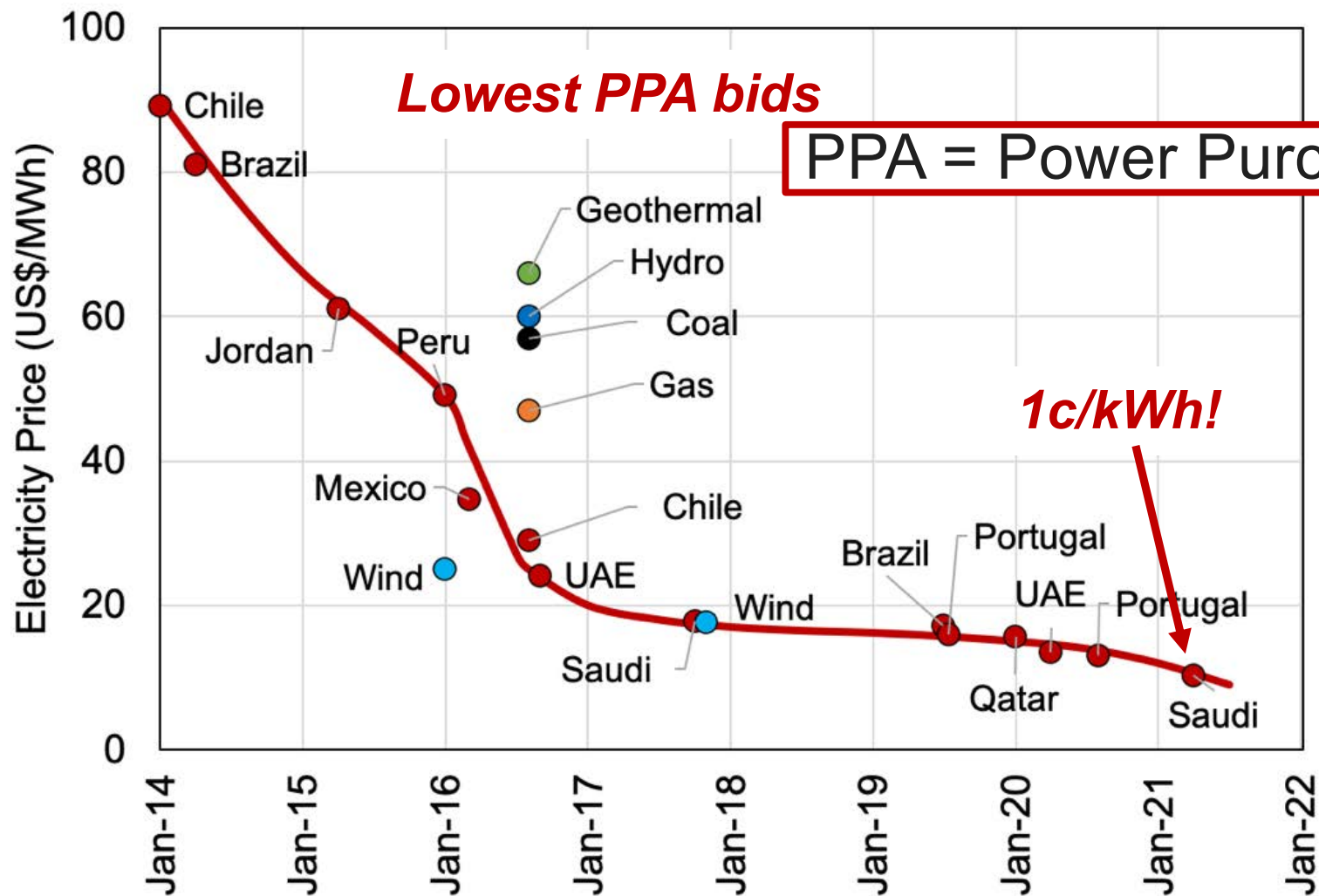


Module cost history



Module cost history

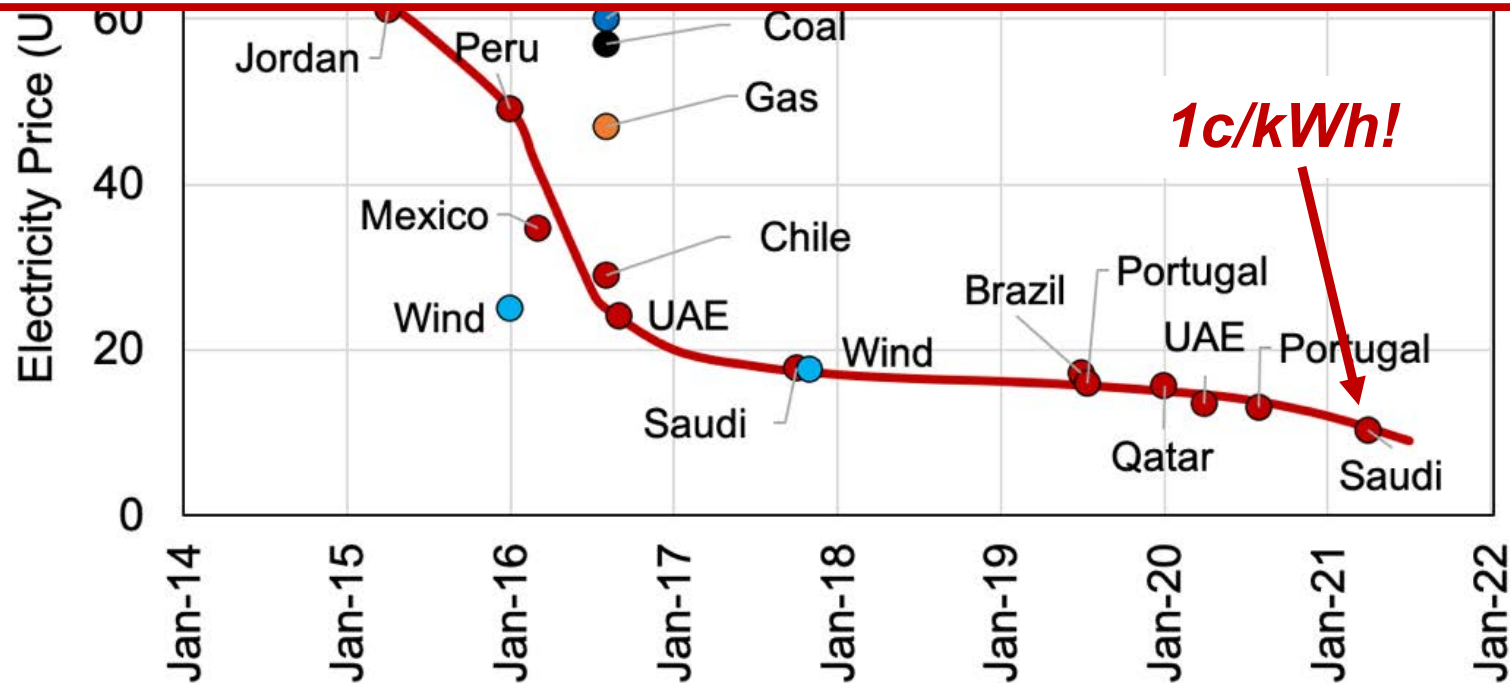




100

International Energy Agency says (2020):

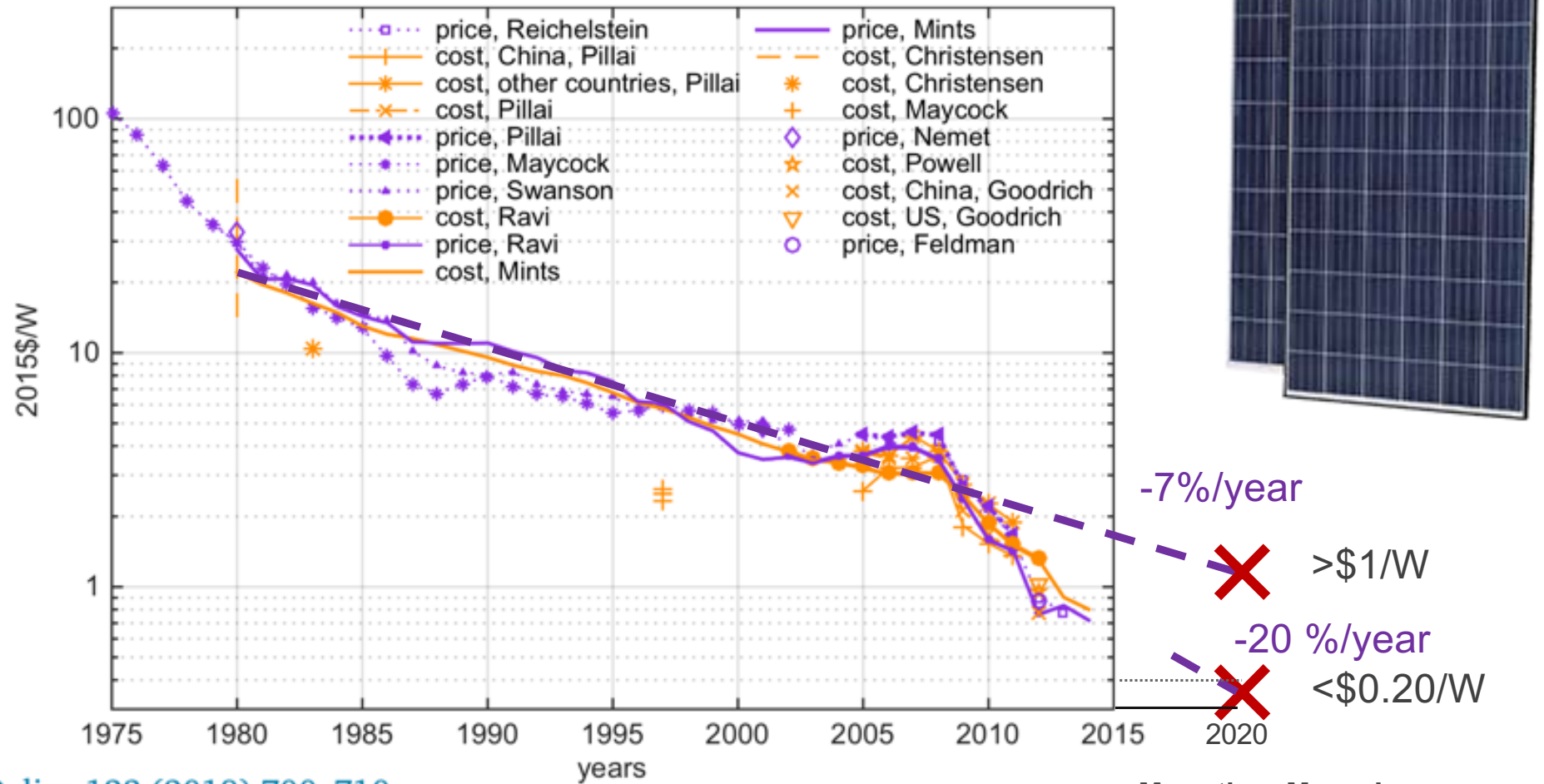
- “solar is now the cheapest source of electricity in most countries”
- “now offer some of the lowest cost electricity ever seen”



Part 2: How cheap can solar become?



History of PV cost/price reduction

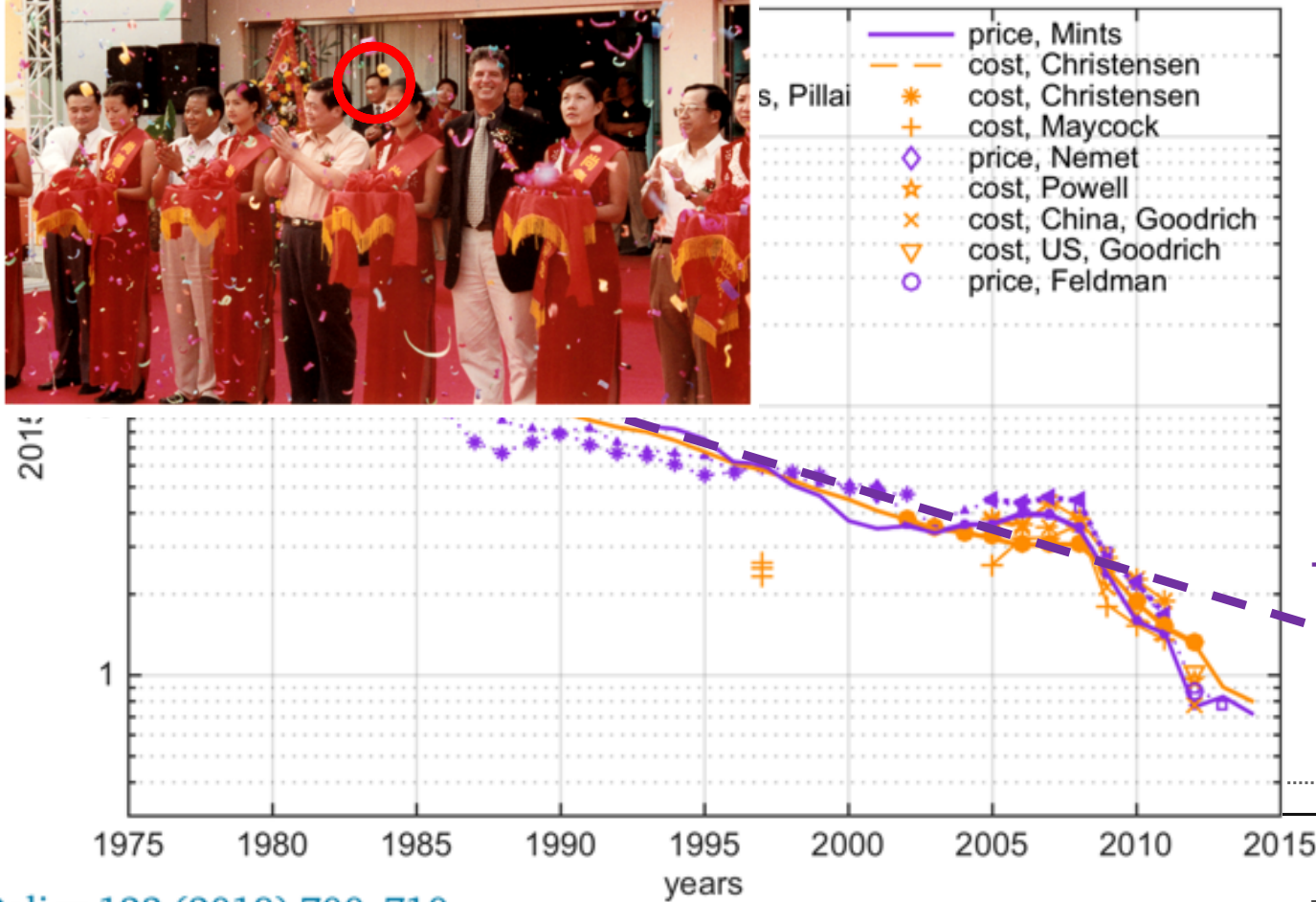


Energy Policy 123 (2018) 700–710

More than Moore!



uction

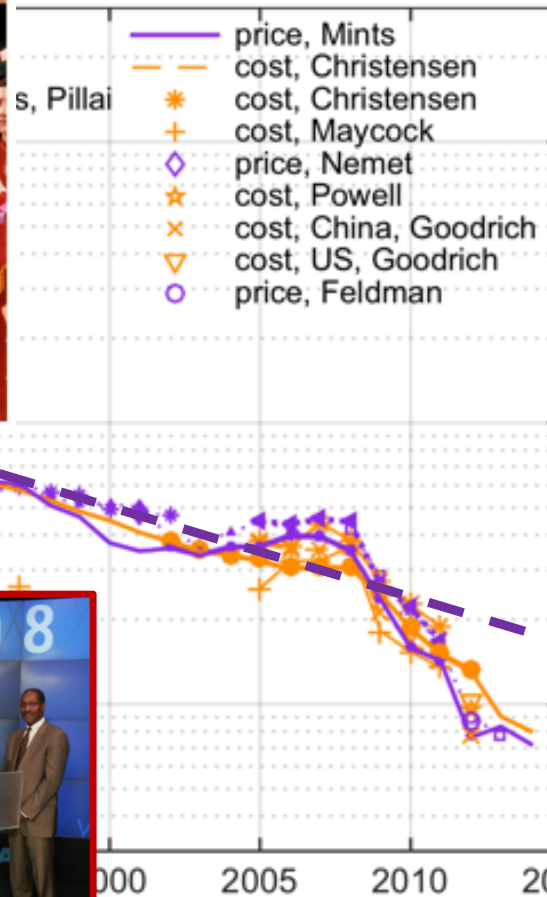


Energy Policy 123 (2018) 700–710

More than Moore!



action



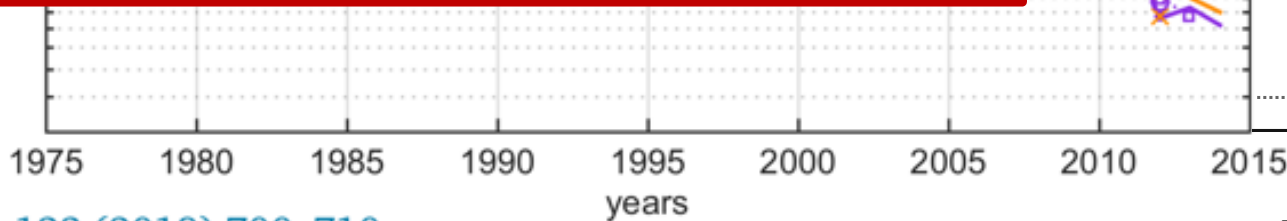
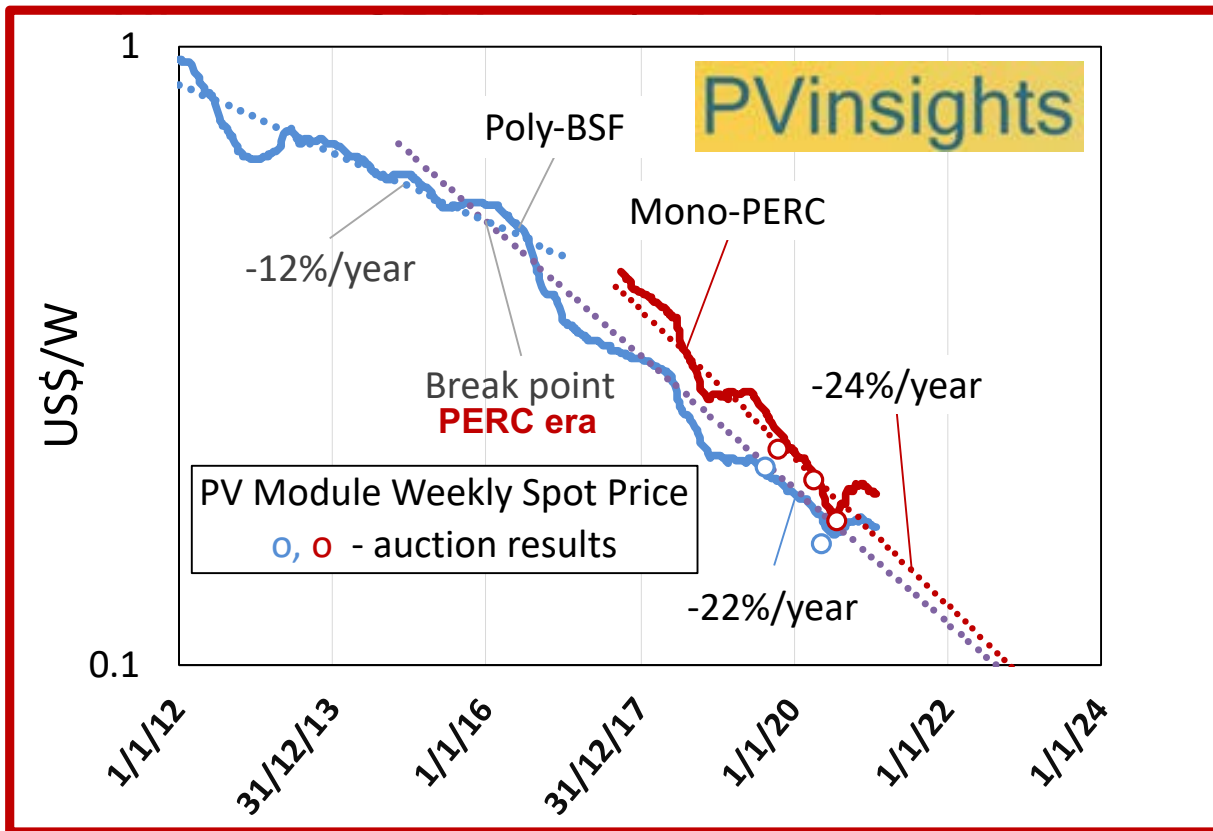
-7%/year

✗ >\$1/W

-20 %/year

✗ <\$0.20/W

More than Moore!



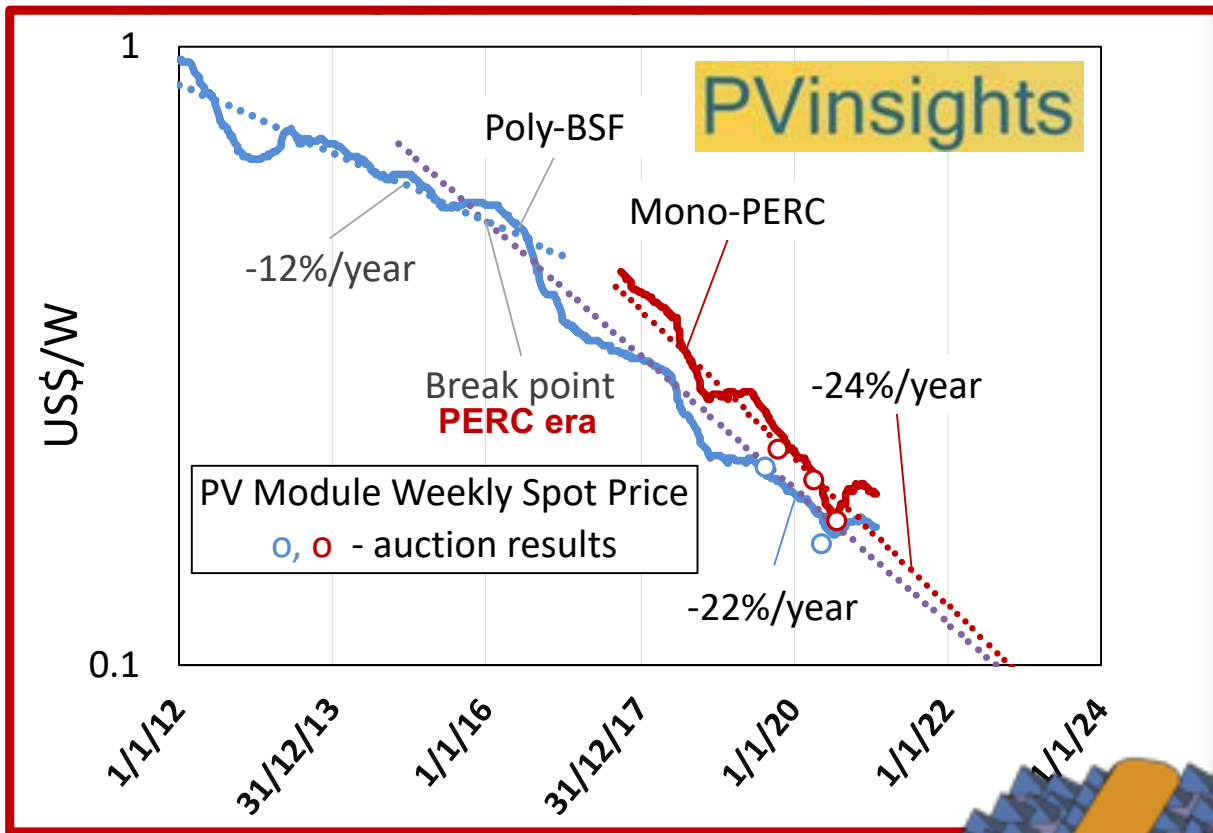
~~×~~ >\$1/W

-20 %/year

~~×~~ <\$0.20/W

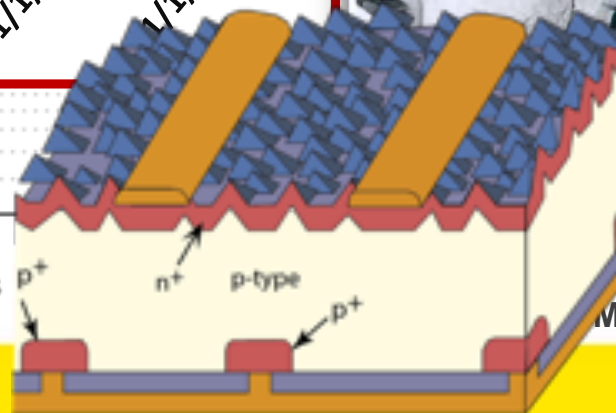
Energy Policy 123 (2018) 700–710

More than Moore!



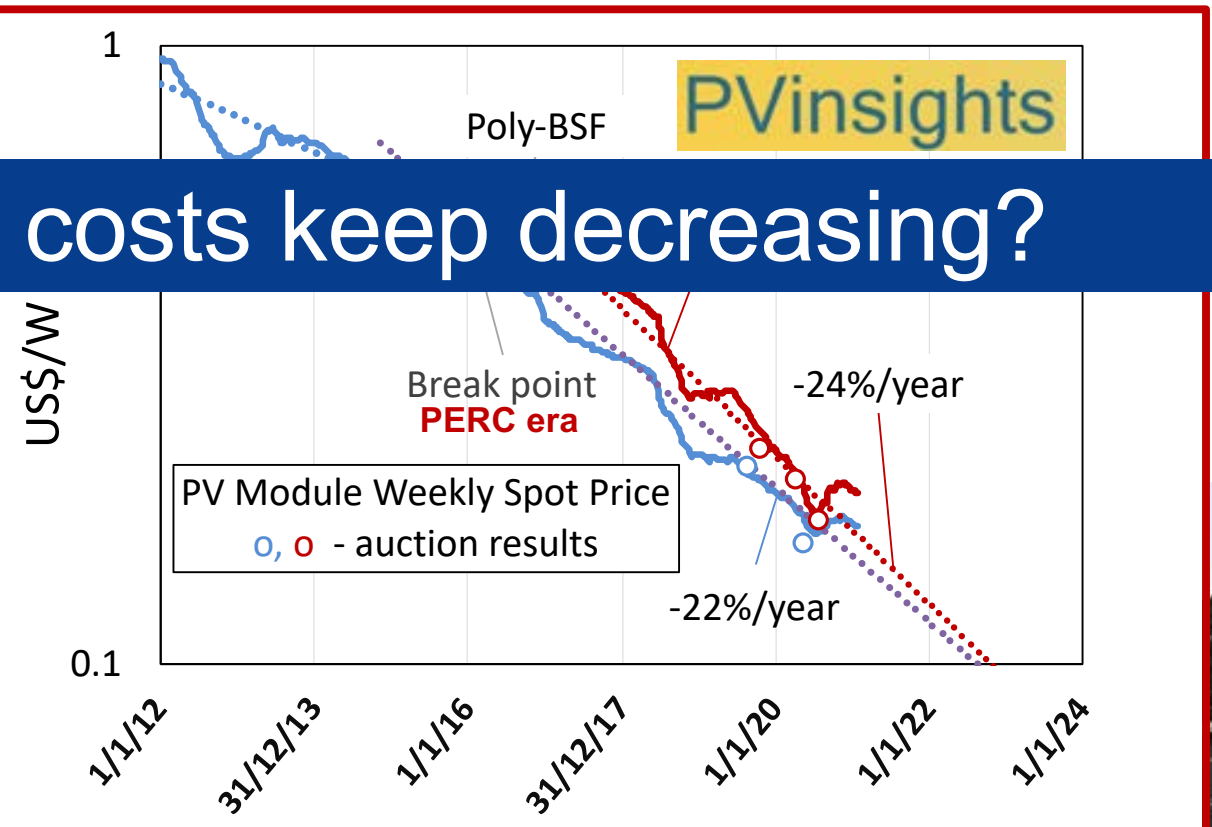
2020

Energy Policy 123 (2018) 700–710

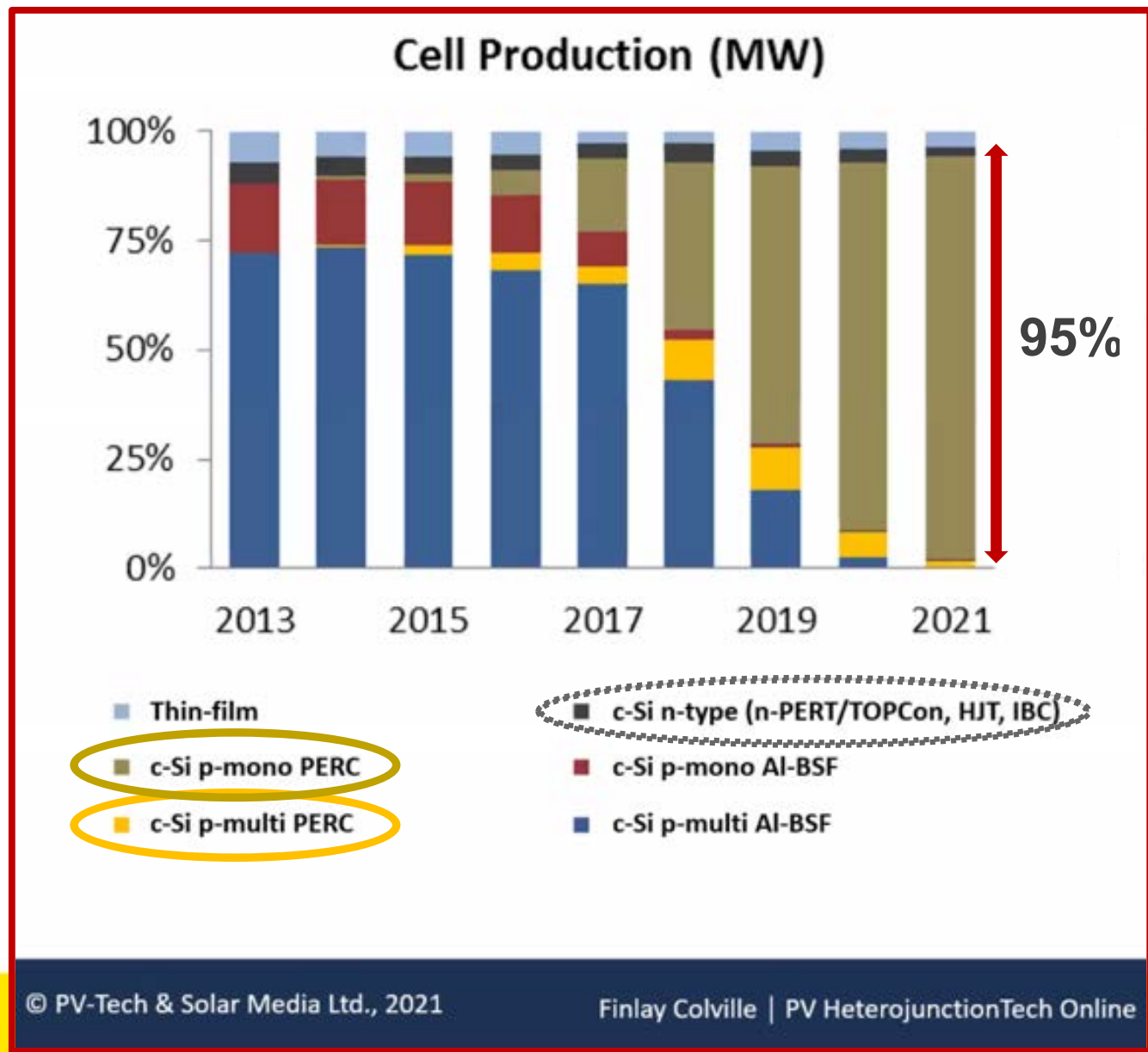


More than Moore!

Part 2: Will PV costs keep decreasing?



PERC transforms industry!



Process Optimization of Ingot Pulling Technology



Continuous increase of feeding rate

- Large scale thermal field
- RCz ingot pulling technology (applied since 2013)

60kg
/crucible

175kg
/crucible

700kg
/crucible

1500kg+
/crucible

High speed ingot pulling technology

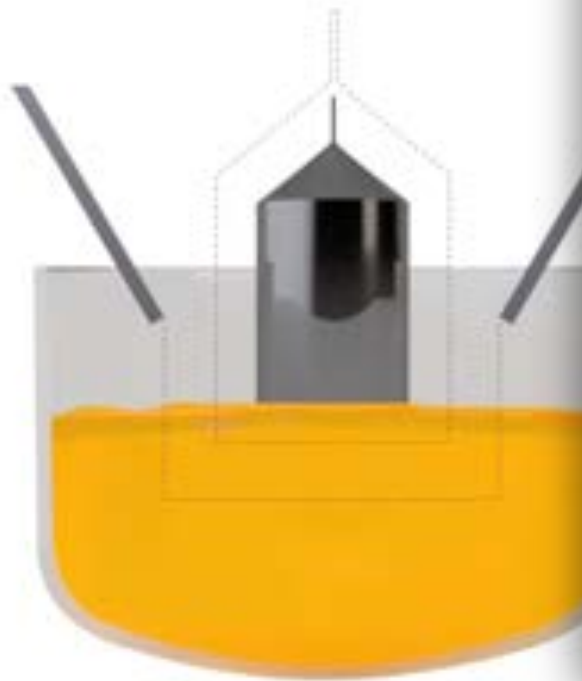
- Pulling speed increased 80%+ since 2013

Production line automation

- Automatic control system
- Automatic loading technology
- Automatic edge cleaning system



Process Optimization



- Automatic control system
- Automatic loading technology
- Automatic edge cleaning system

LONGI

Technology

(applied since 2013)

1500kg+
Crucible



Process Optimization

LONGi

Technology

Mono Wafer Cost Reduction

LONGi

Mass Production Cost Down



(applied since 2013)

1500kg+
Crucible



UNSW
SYDNEY

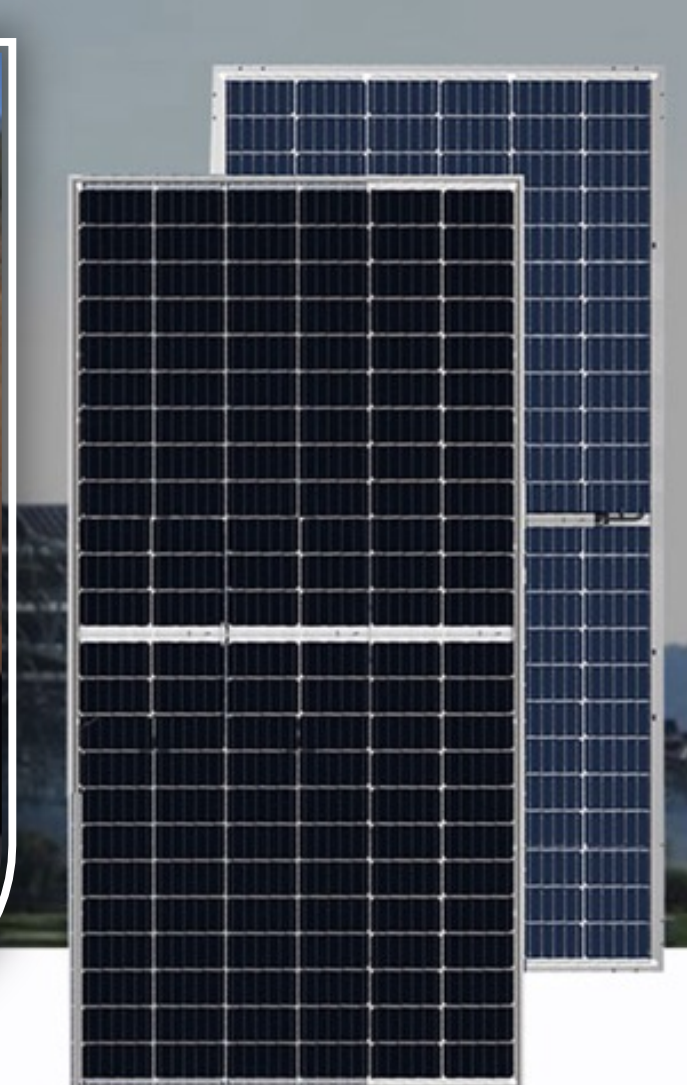
PERC offers new functionalities: Cheap bifacial cells!



PERC : Cheap bifacial cells! Half-cut cells, shingling

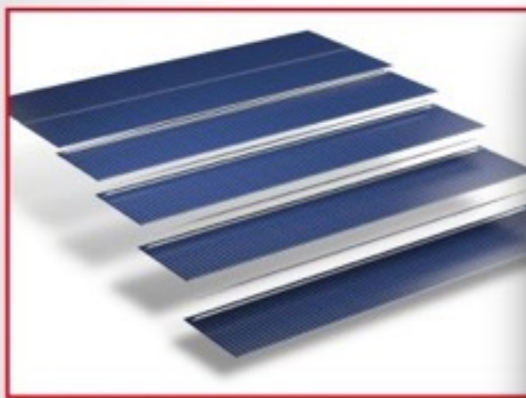


Honda Dream 1996



PERC : Cheap bifacial cells! Half-cut cells, shingling (now tiling)

Shingled Solar Modules



Source: PVTECH

Ribbon Bonding

Module Efficiency Improvement: Smart Soldering

LONGi Using integrated segmented ribbons.

Module efficiency increasing by 0.3% compared to conventional MBB product.

Triangular section
maximizes light capturing

Flat section
achieve dense soldering with low stress

Micro-gap
The best combination of high efficiency,
reliability and cost

LONGi

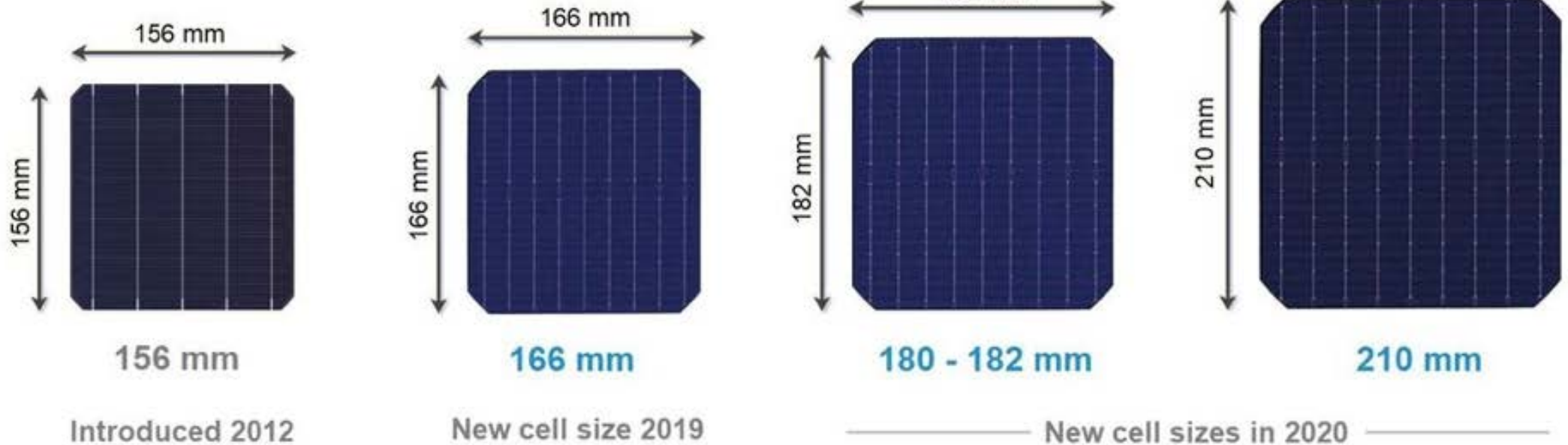
Honda Dream 1996



PERC : Cheap bifacial cells! Half-cut cells, shingling



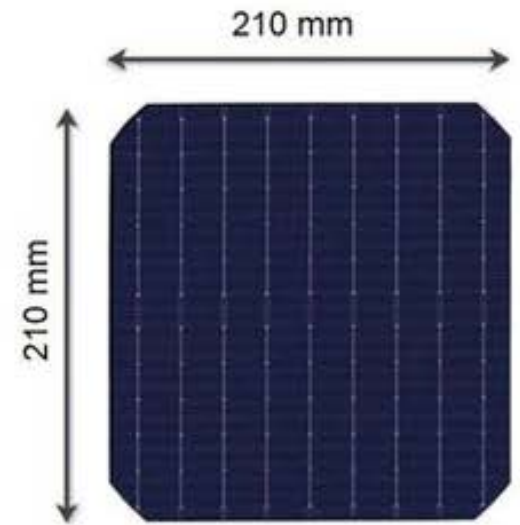
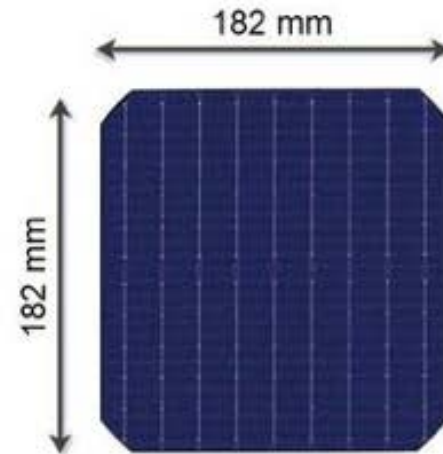
New Solar PV Cell Sizes



PERC : Cheap bifacial cells! Half-cut cells, shingling



Solar PV Cell Sizes



156 mm

166 mm

180 - 182 mm

210 mm

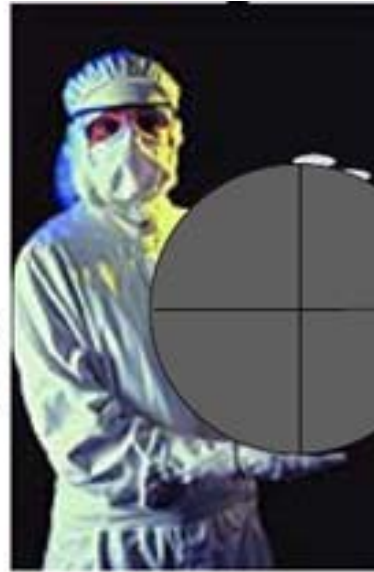
Introduced 2012

New cell size 2019

New cell sizes in 2020

Size trend of silicon wafer in semiconductor and PV industry





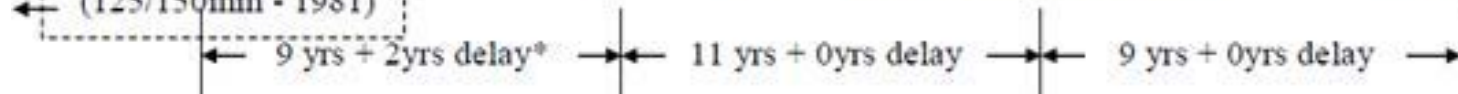
200mm/1990

300mm/2001

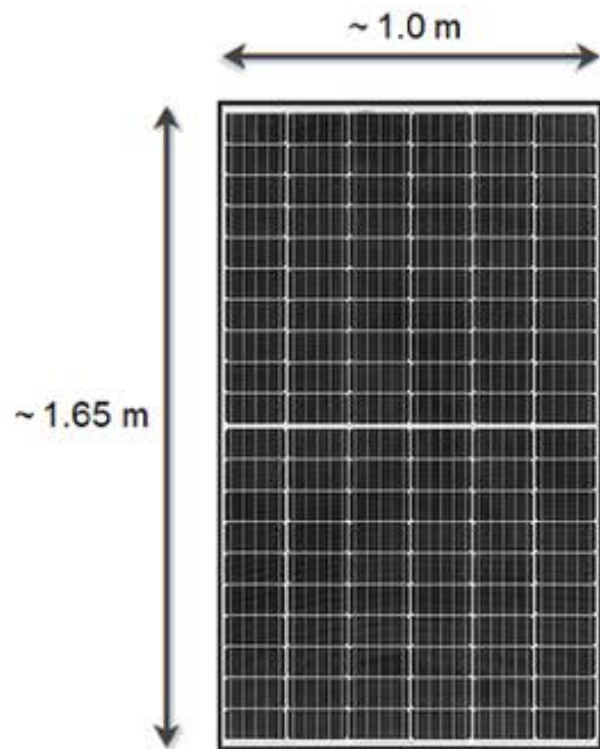
450mm/2012

675mm/2019?

← (125/150mm - 1981)

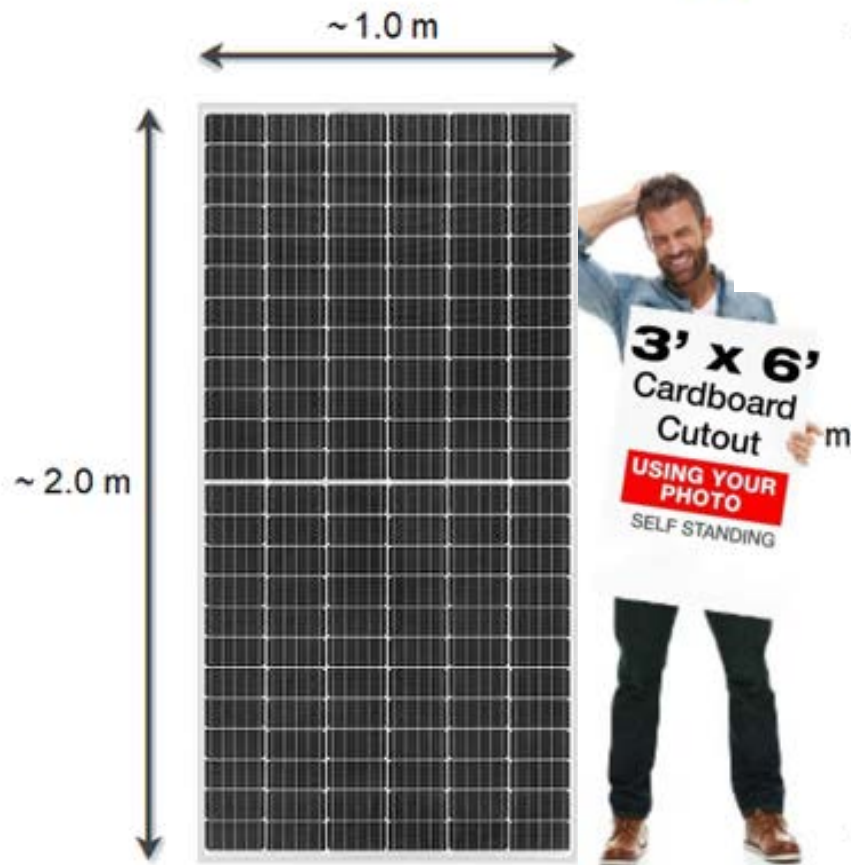


Solar Panel Size Vs Power Output



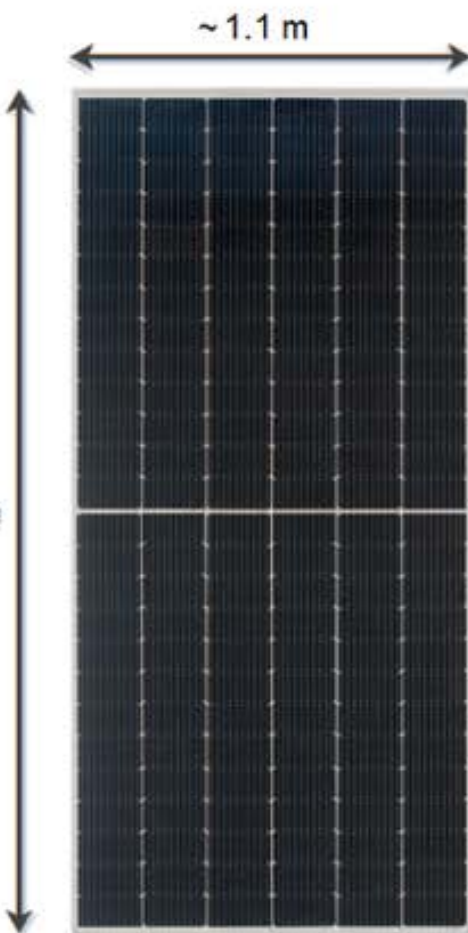
60 cells (120 HC)

300W - 380W



72 cells (144 HC)

350W - 450W



78 cells (156 HC*)

450W - 600W+



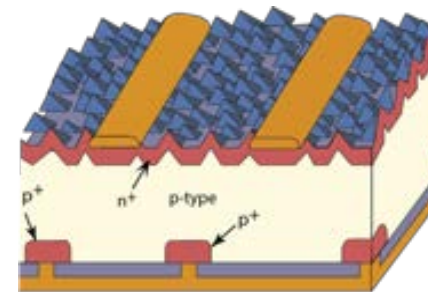
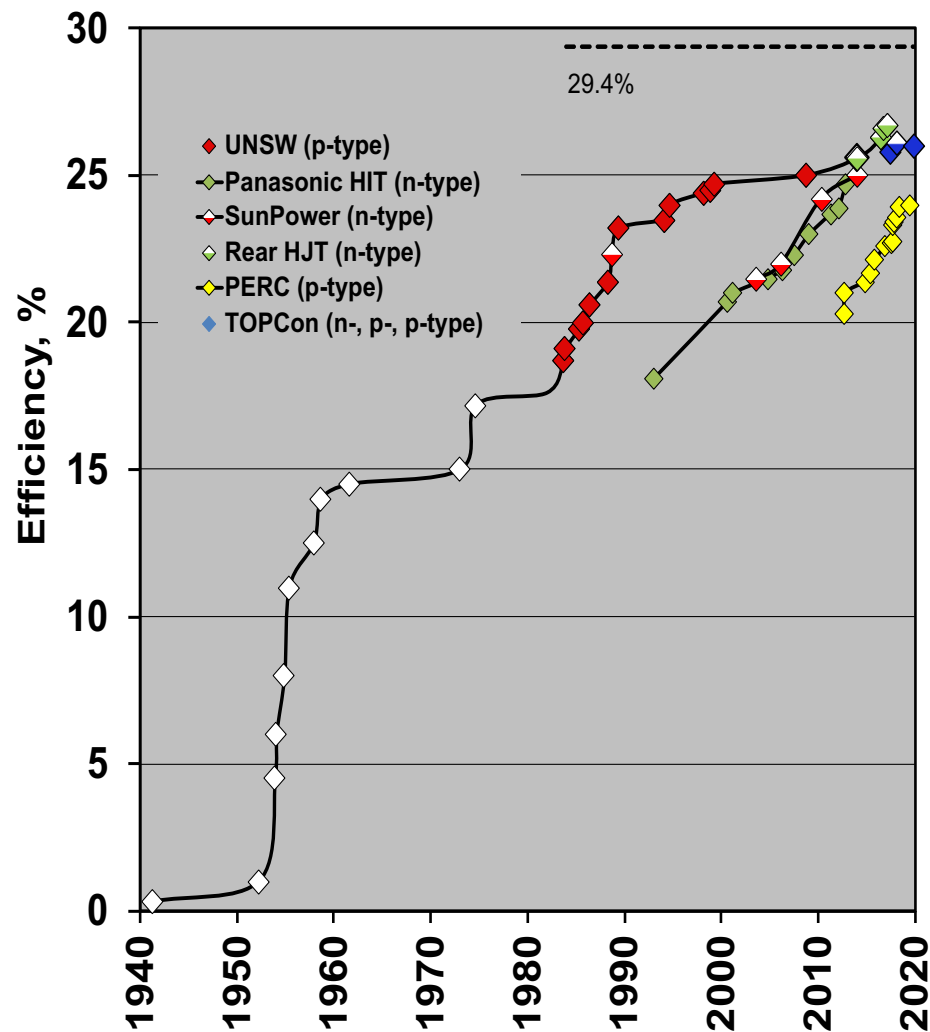




Part 3: Longer term cell technology?

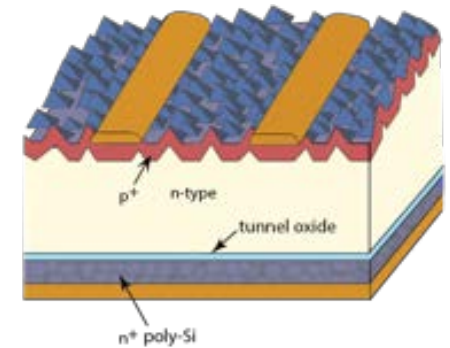


Contending technologies

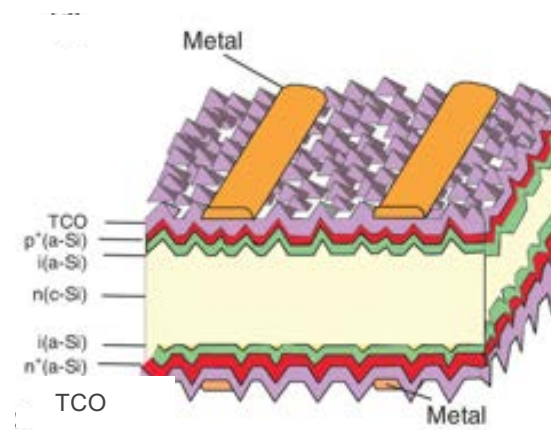


PERC, n-PERT

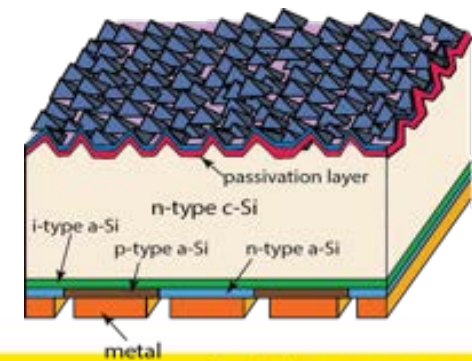
TOPCon



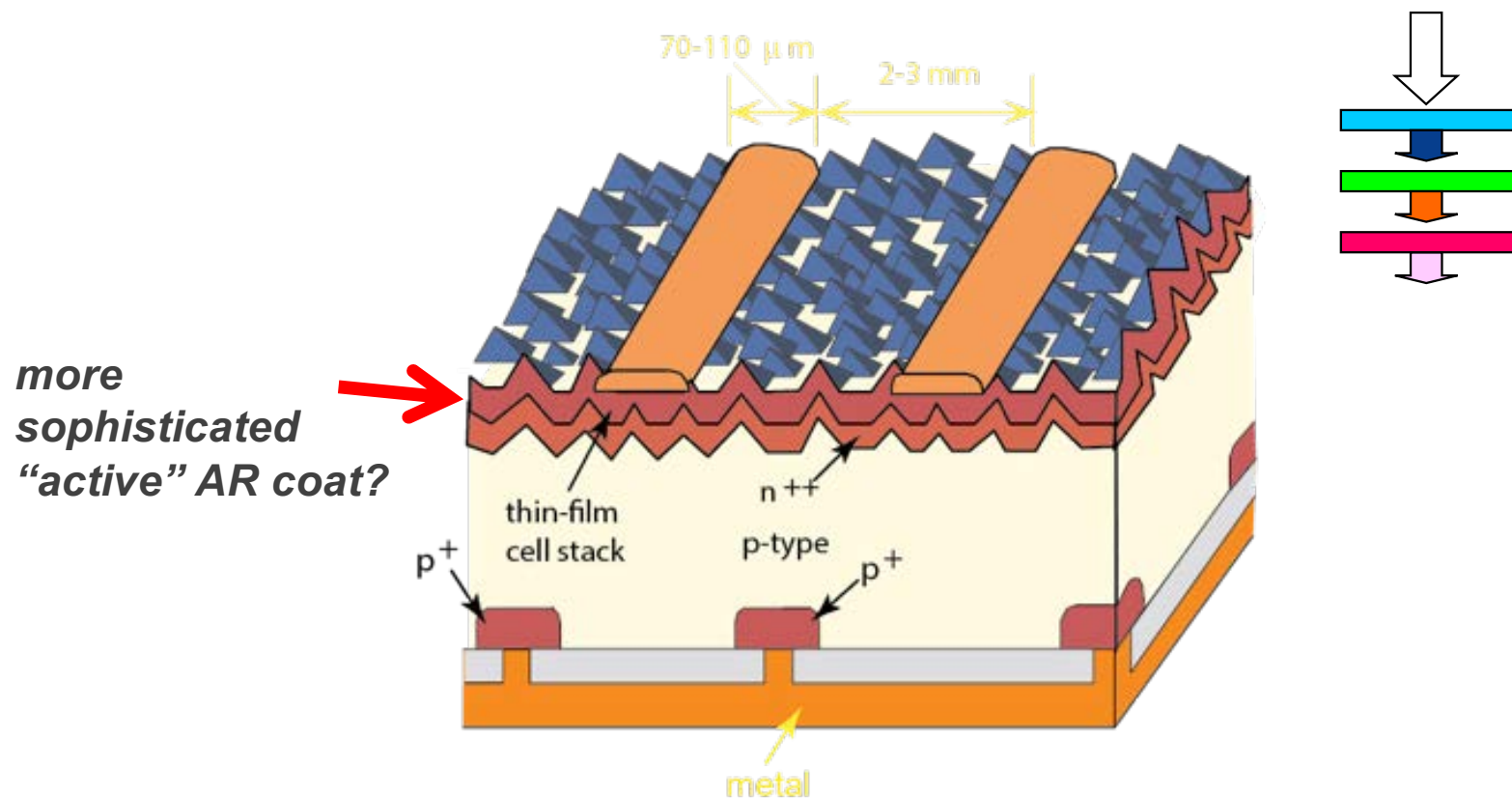
HJT



IBC

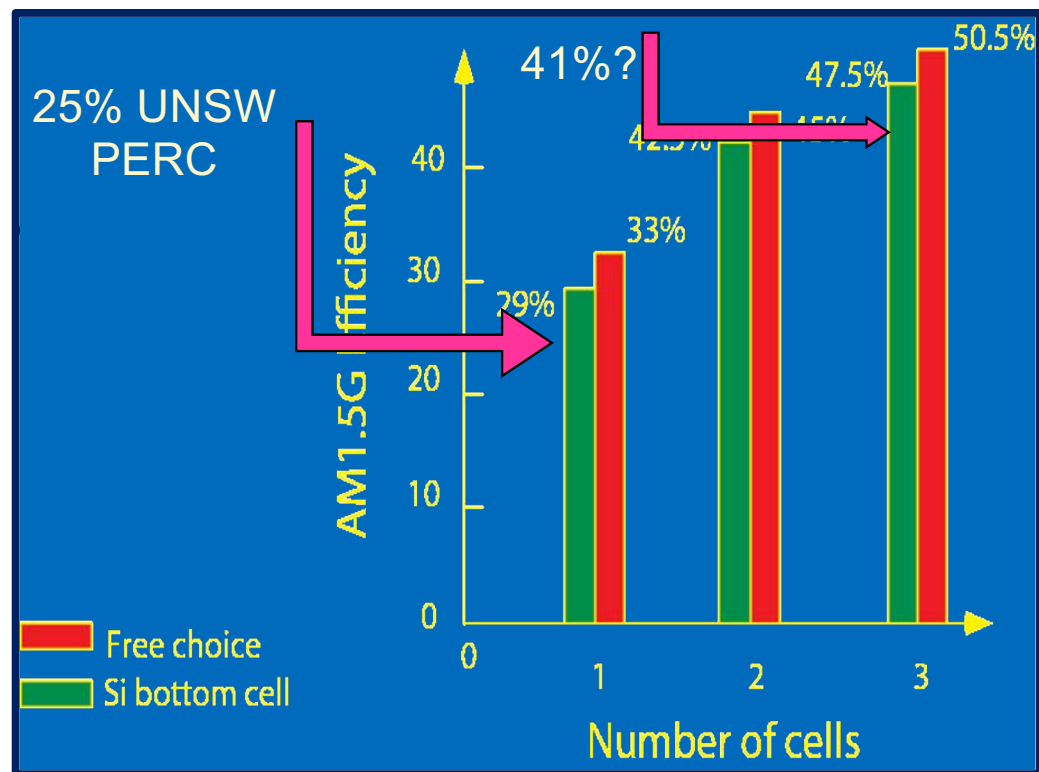
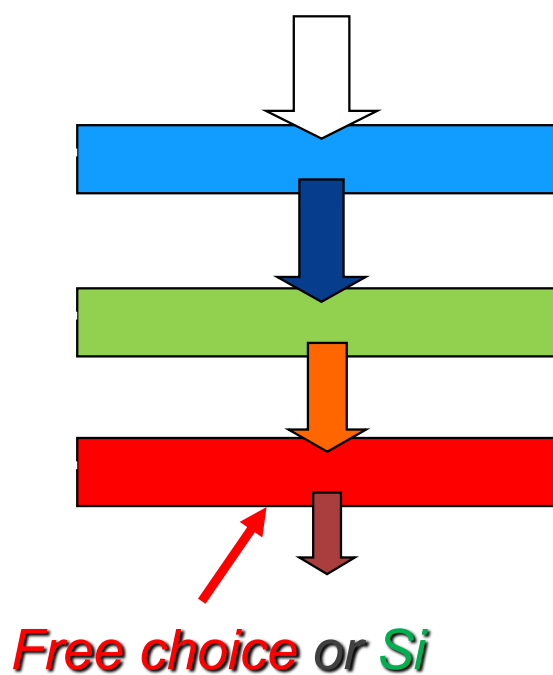


What comes after PERC? – longer term



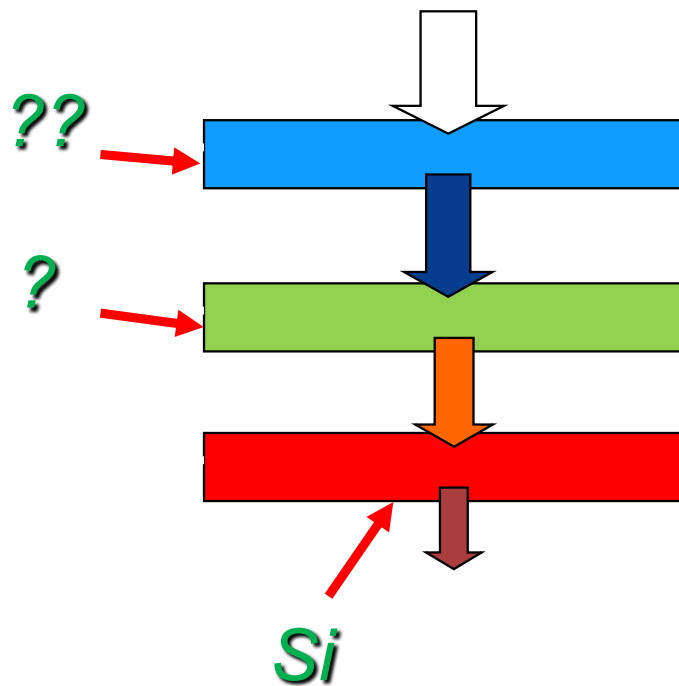
Supercharged tandem PERC?

What comes after PERC? – longer term

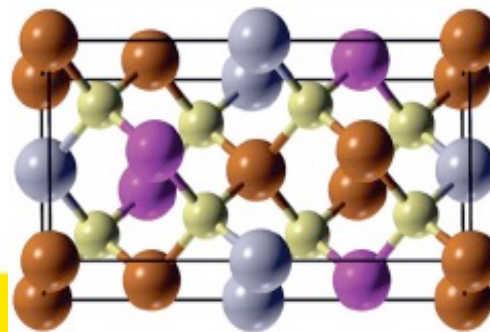


What comes after PERC? – longer term

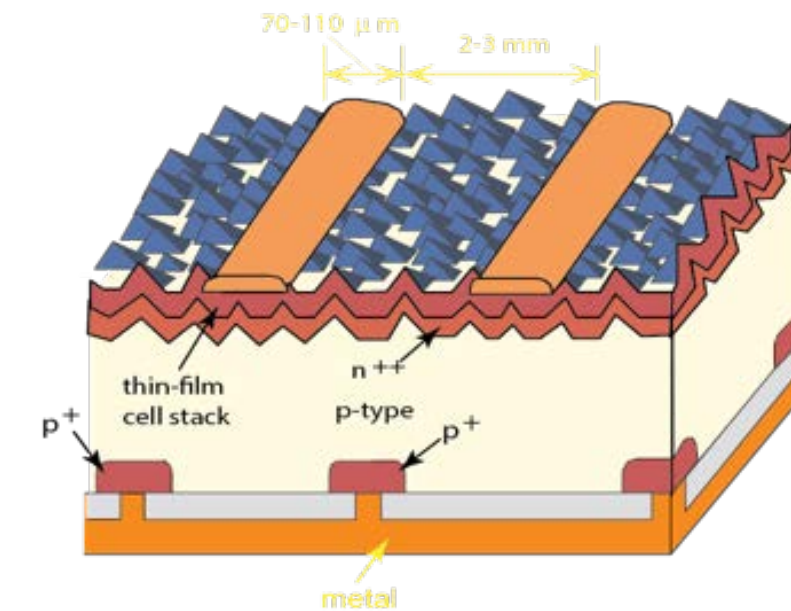
Like silicon, ? needs to be abundant, non-toxic, stable, efficient (>20%)



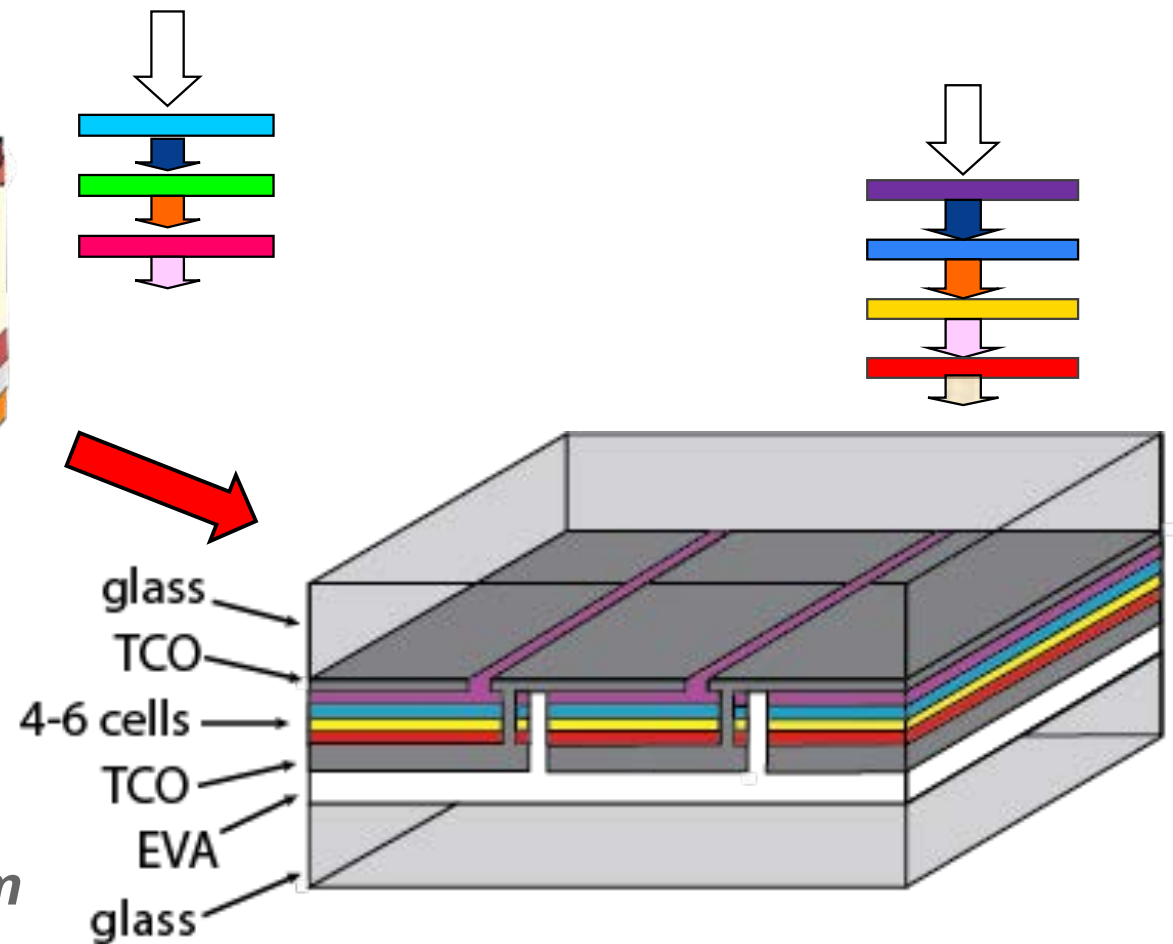
	<i>Perovskite</i>	✓	×	×	✓
	<i>Organics (OPV)</i>	✓	✓	×	×
II-VI {	<i>Cu₂Zn(Sn:Si)S₄</i>	✓	✓	✓	×
	<i>Cu(In:Ga)(S:Se)₂</i>	×	?	✓	×
	<i>(Cd:Zn:Mg)(Se:Te)</i>	×	×	✓	?
III-V	<i>(Al:Ga:In)(As:P)</i>	×	?	✓	?



What then? – *the end for silicon?*



Si - 3 cell tandem

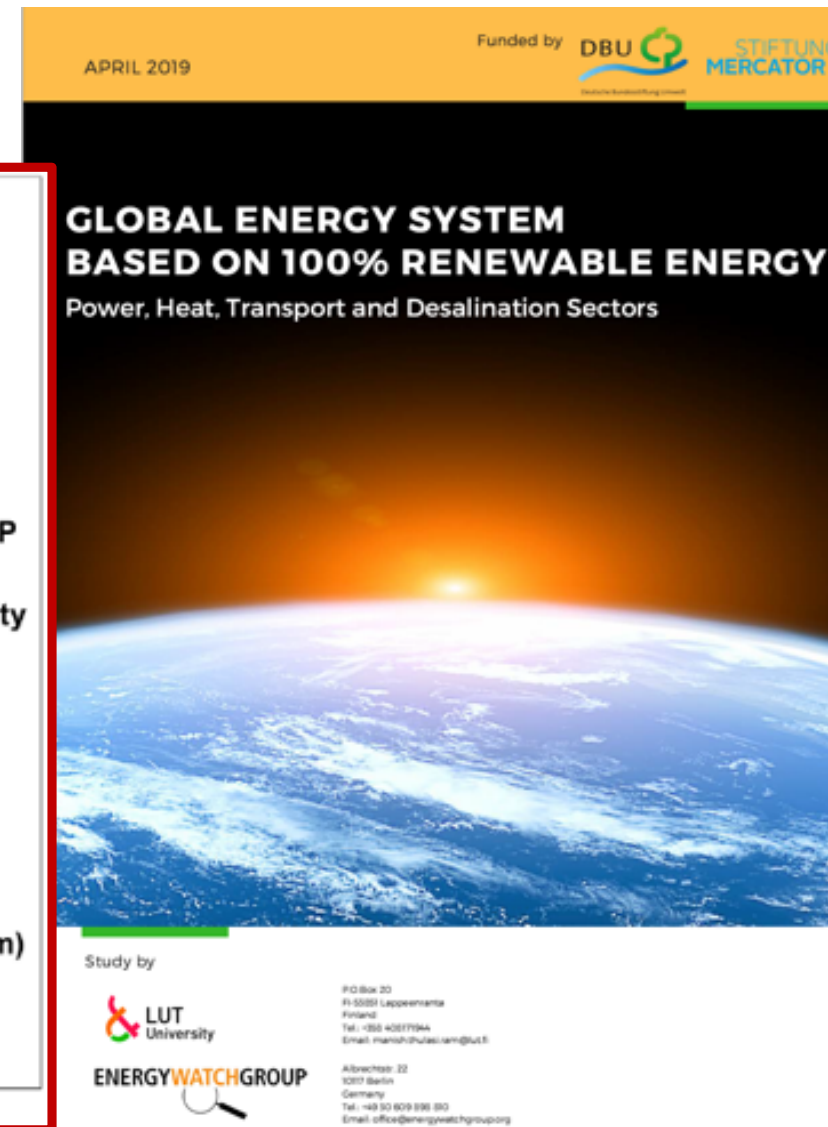
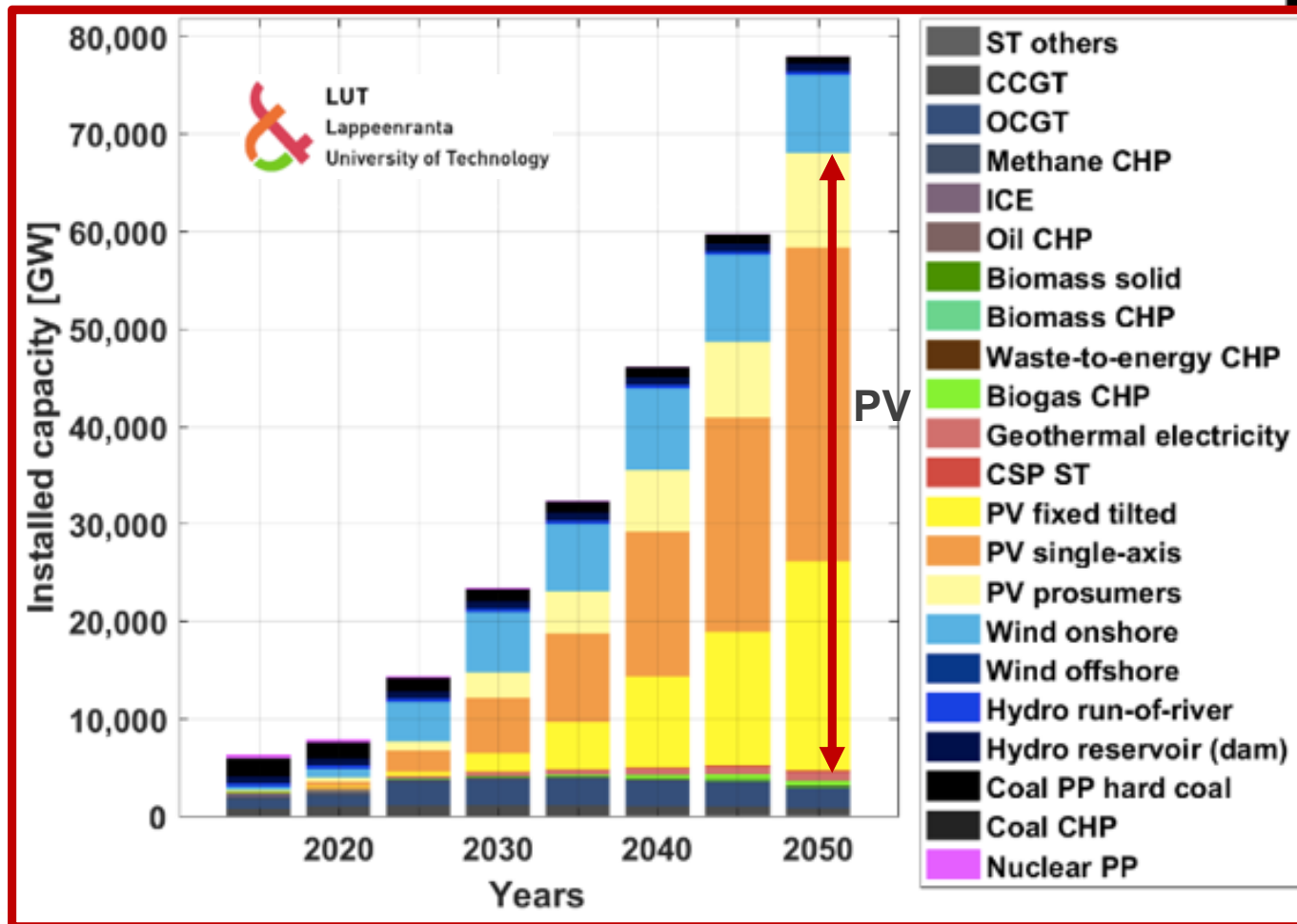


4-6 cell thin-film tandem

Part 4: Can solar power the world?



Recent studies suggest so!



Energy 227 (2021) 120467

Pumped hydro storage







300MW, 450MWh Li-ion battery

GREEN HYDROGEN COST REDUCTION

**SCALING UP
ELECTROLYSERS**
TO MEET THE 1.5°C
CLIMATE GOAL

H₂

O₂

RENEWABLE POWER GENERATION COSTS IN 2020

A large industrial steel mill with a glowing hot steel coil being processed by machinery. The scene is filled with smoke and sparks, highlighting the intense heat of the production process. The machinery is complex, with various pipes, valves, and structural elements visible. In the background, two workers in blue uniforms and hard hats are standing near a set of stairs, providing a sense of scale to the massive industrial environment.

Volvo Group and SSAB to collaborate on the world's first vehicles of fossil-free steel

'World first' as hydrogen used to power commercial steel production

“Solar Photovoltaics: Power Source for the Future”

- . *Si PV to become “insanely cheap”!*
(Ramez Naam)
- . *PERC accelerates change*
- . *US10c/Watt, 22-23% efficient modules within next few years*
(+1c/kWh electricity prices)!
- . *Solar with wind, storage and H₂ will play major role mitigating global warming.*



ARENA

