

“Recent trends in photovoltaics”

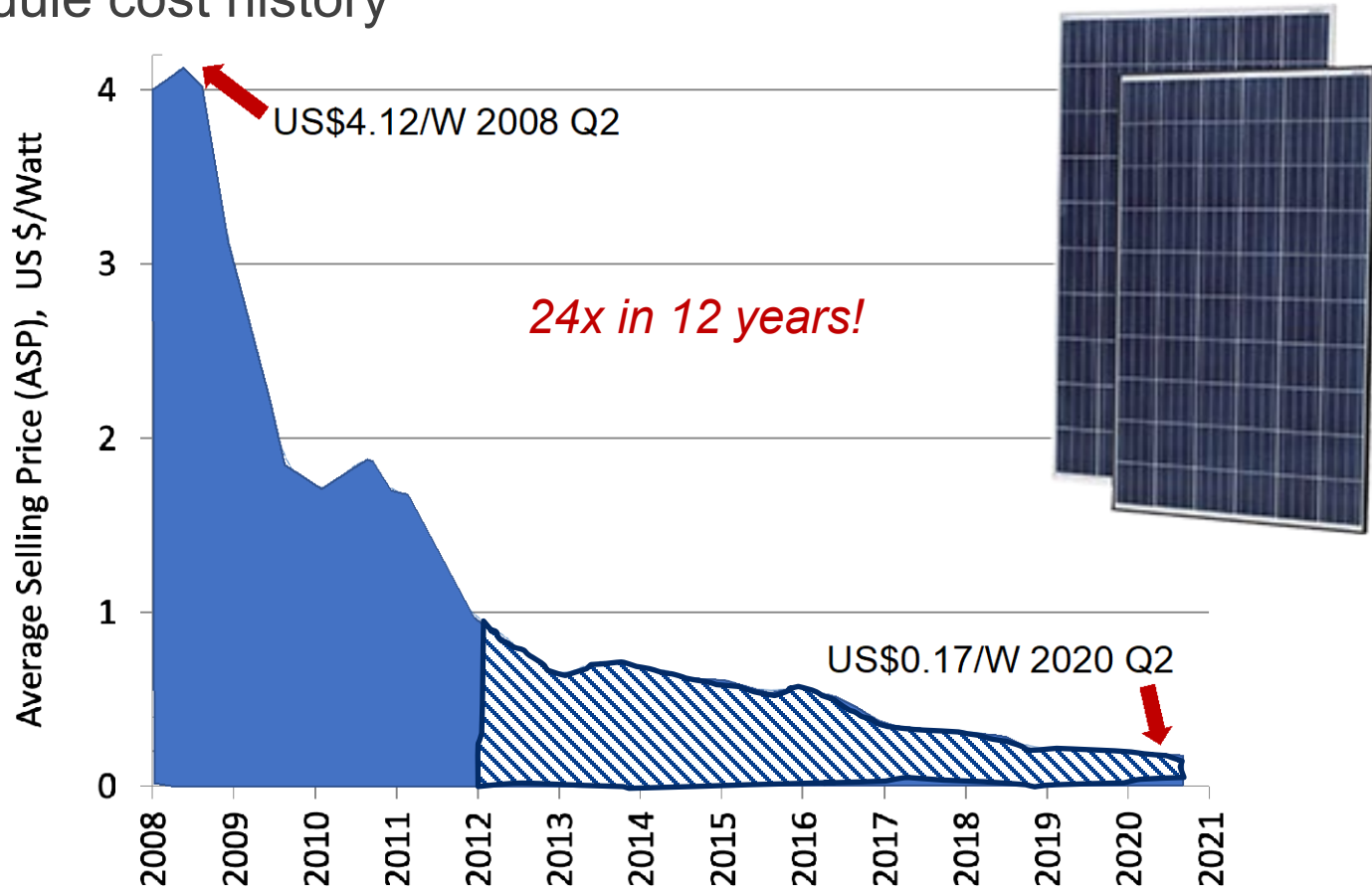
Martin Green, UNSW Sydney



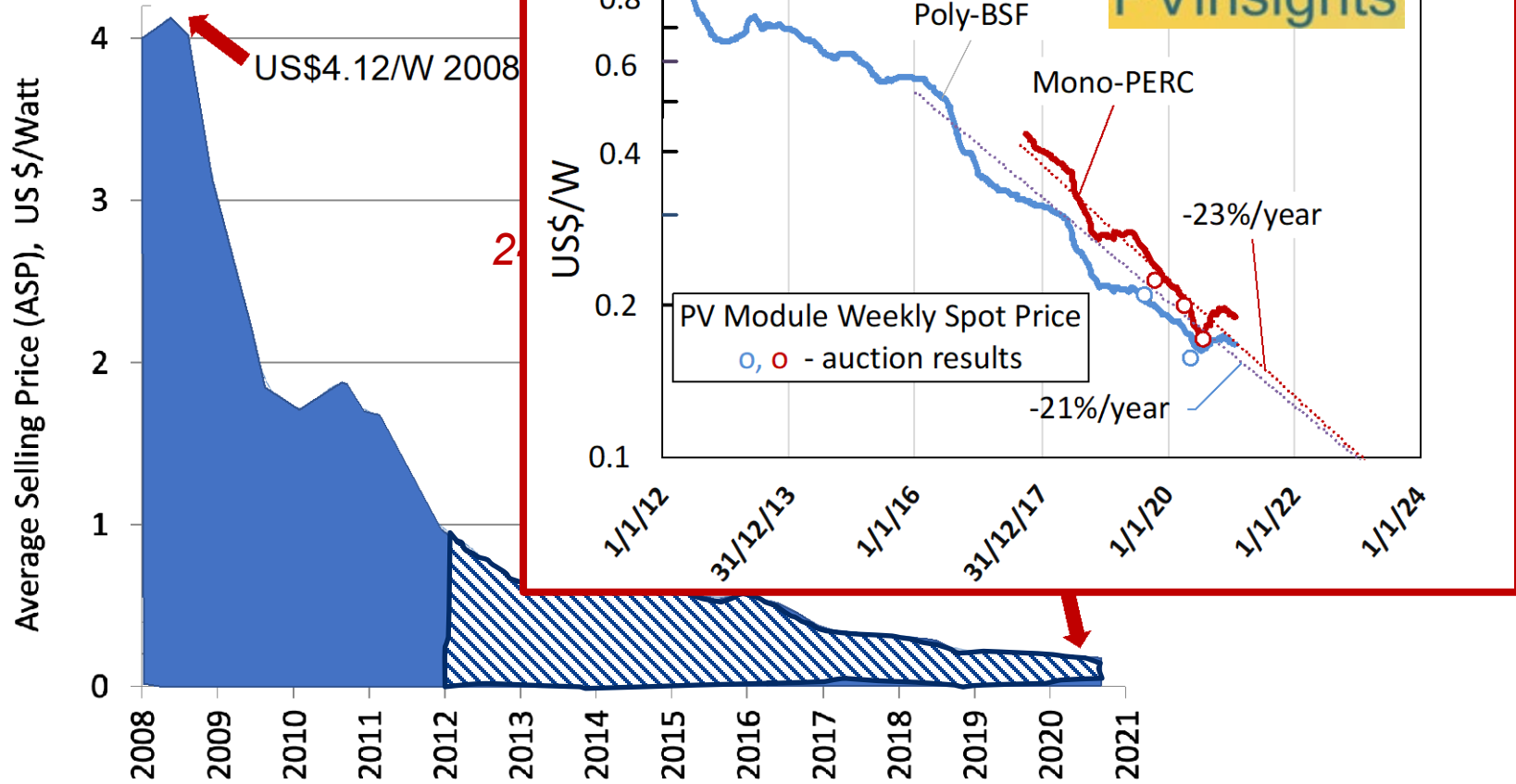
Part 1: “Big picture” developments



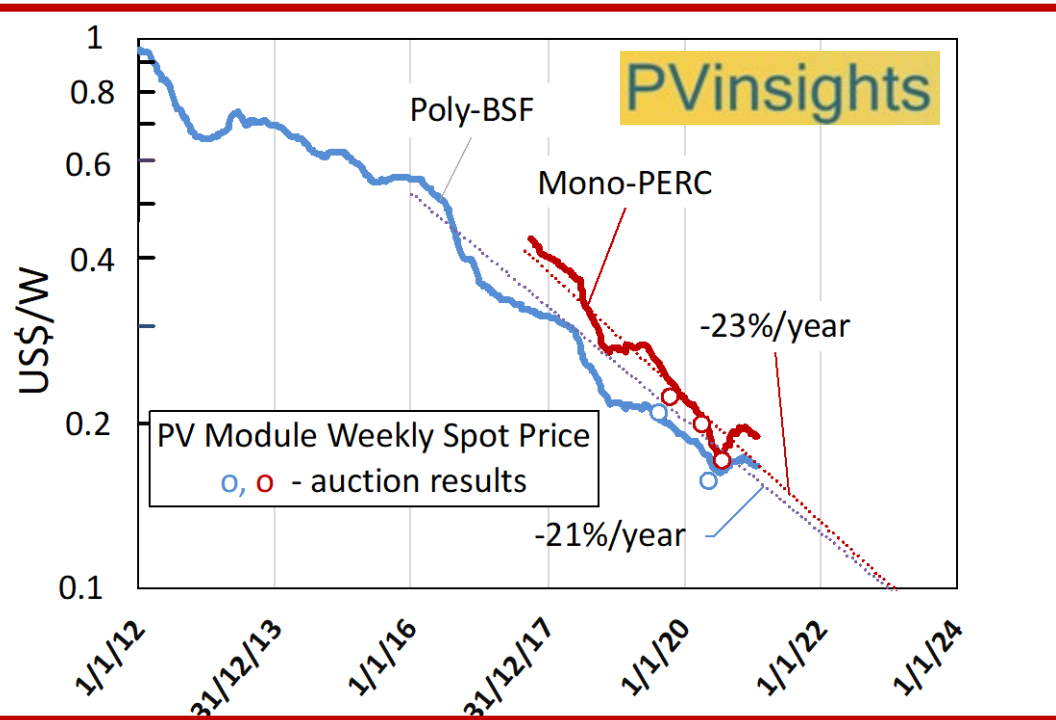
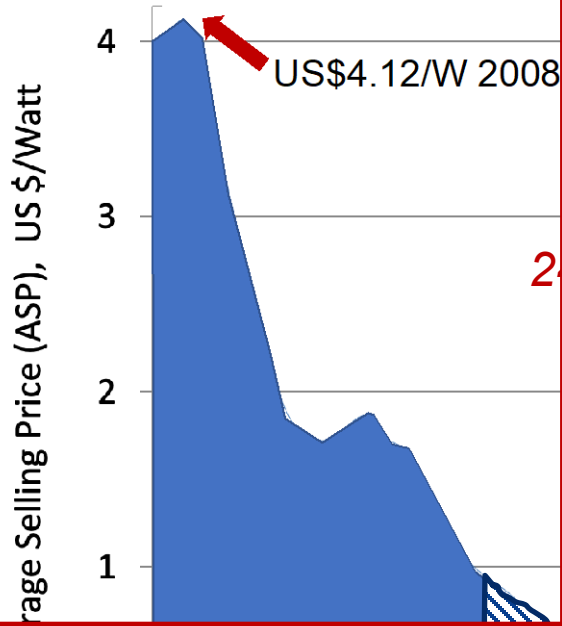
Module cost history



Module cost history

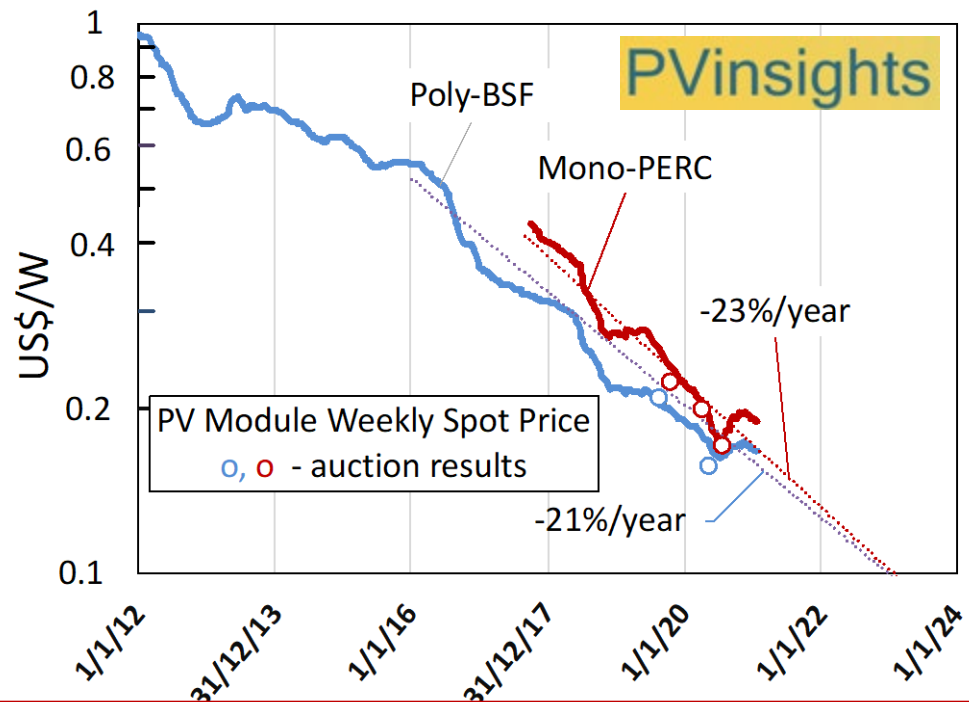
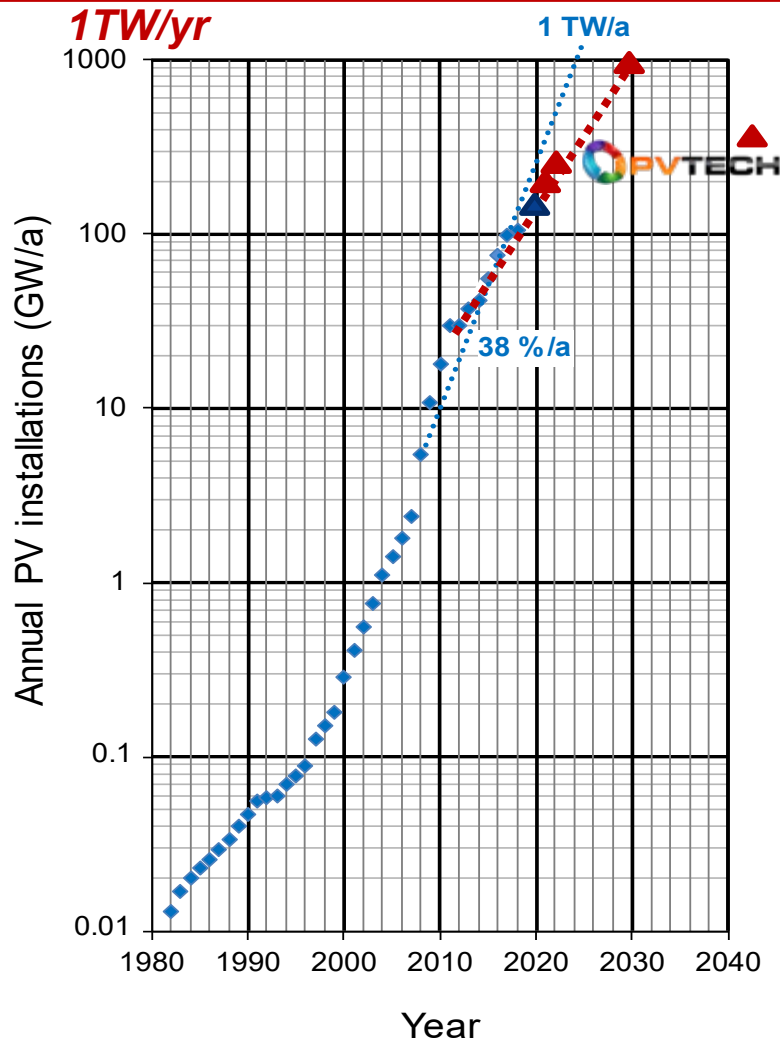


Module cost history



International Energy Agency says (2020):

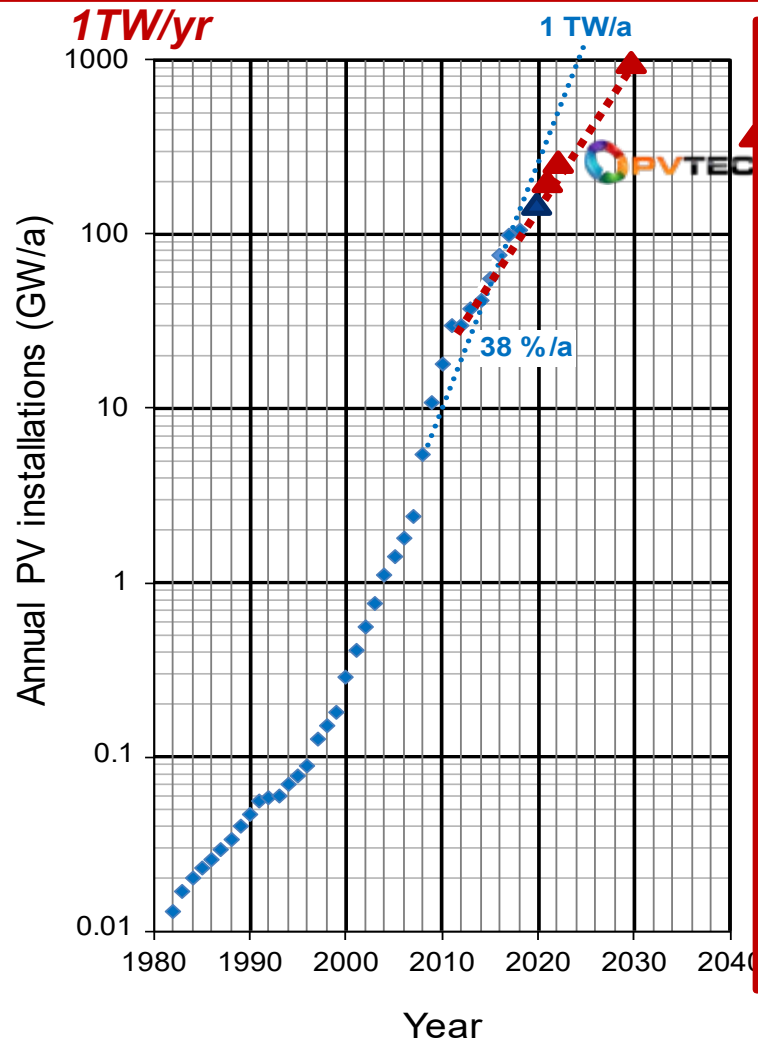
- *“solar is now the cheapest source of electricity in most countries”*
- *“now offer some of the lowest cost electricity ever seen”*



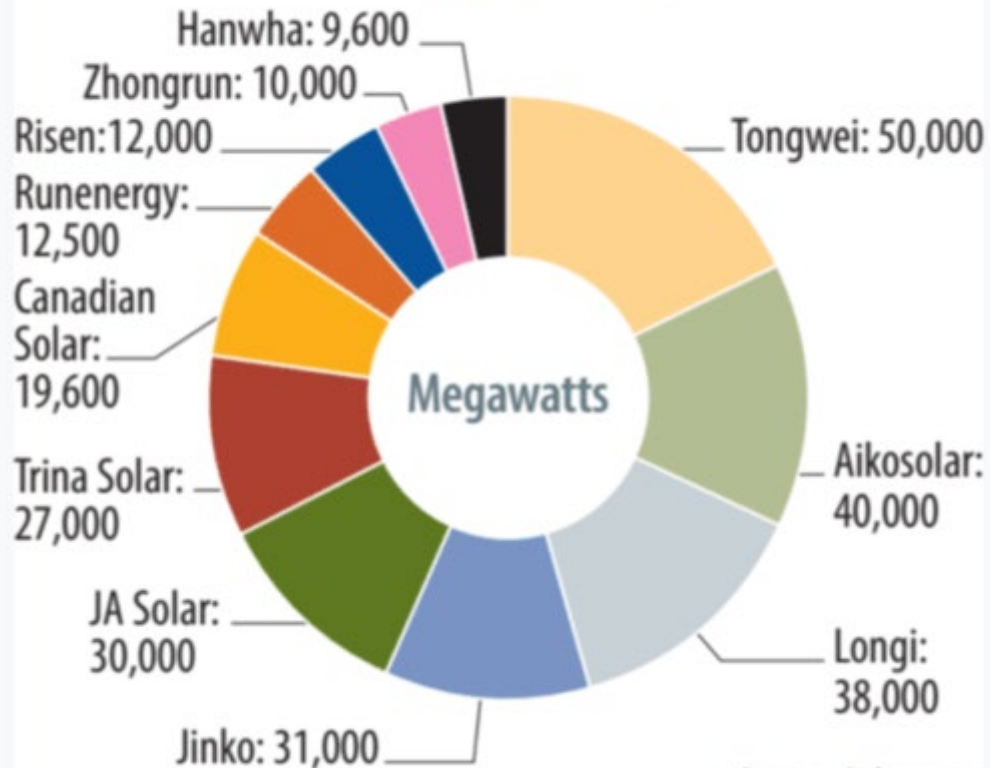
says (2020):

source of electricity in most countries”

est cost electricity ever seen”



Cell manufacturing capacity share

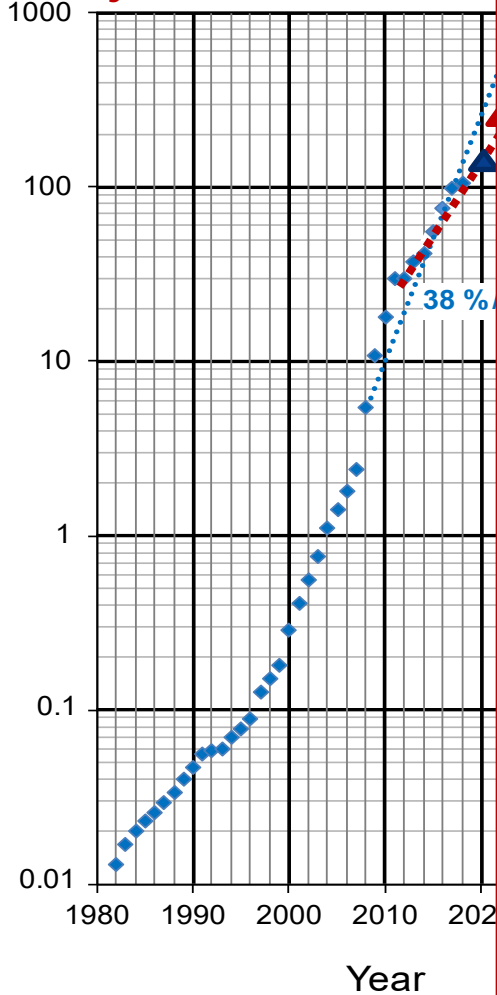


Source: Solarzoom

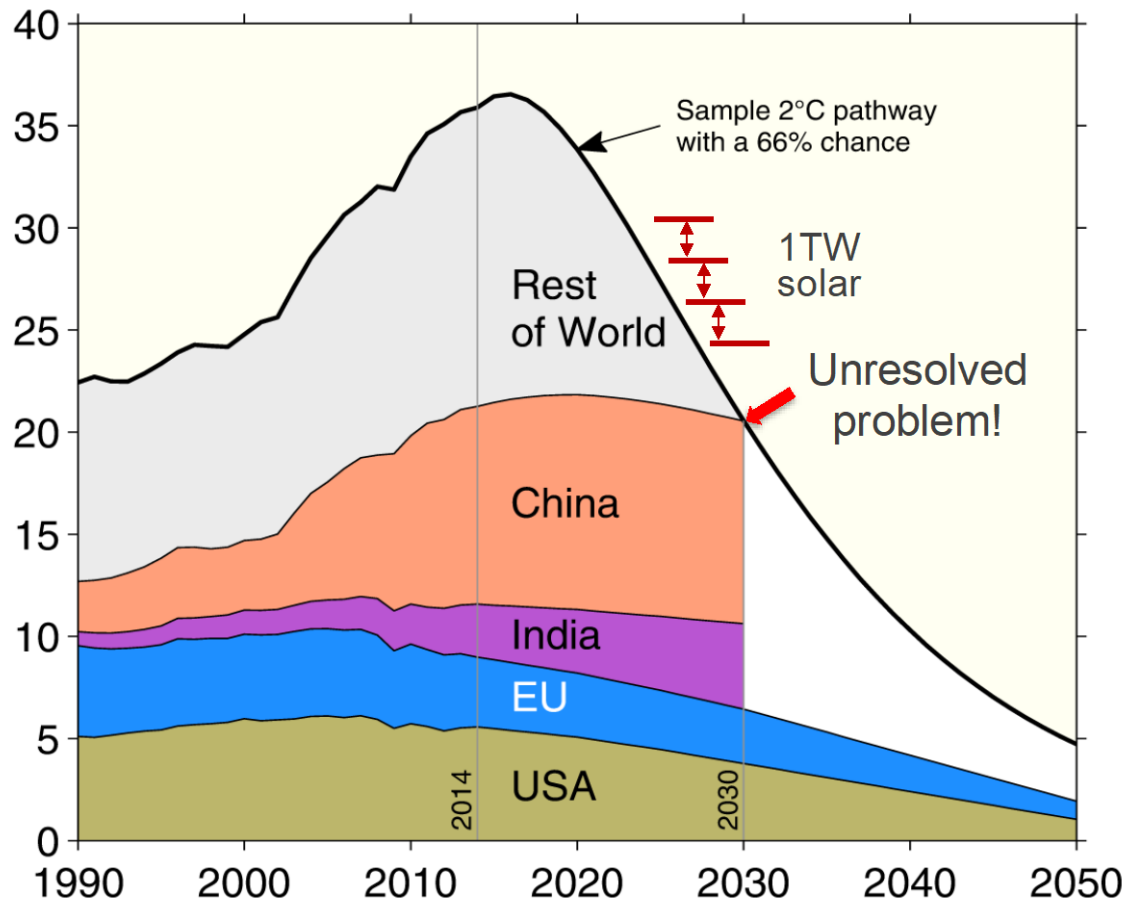
Best cost electricity ever seen

1TW/yr

Annual PV installations (GW/a)



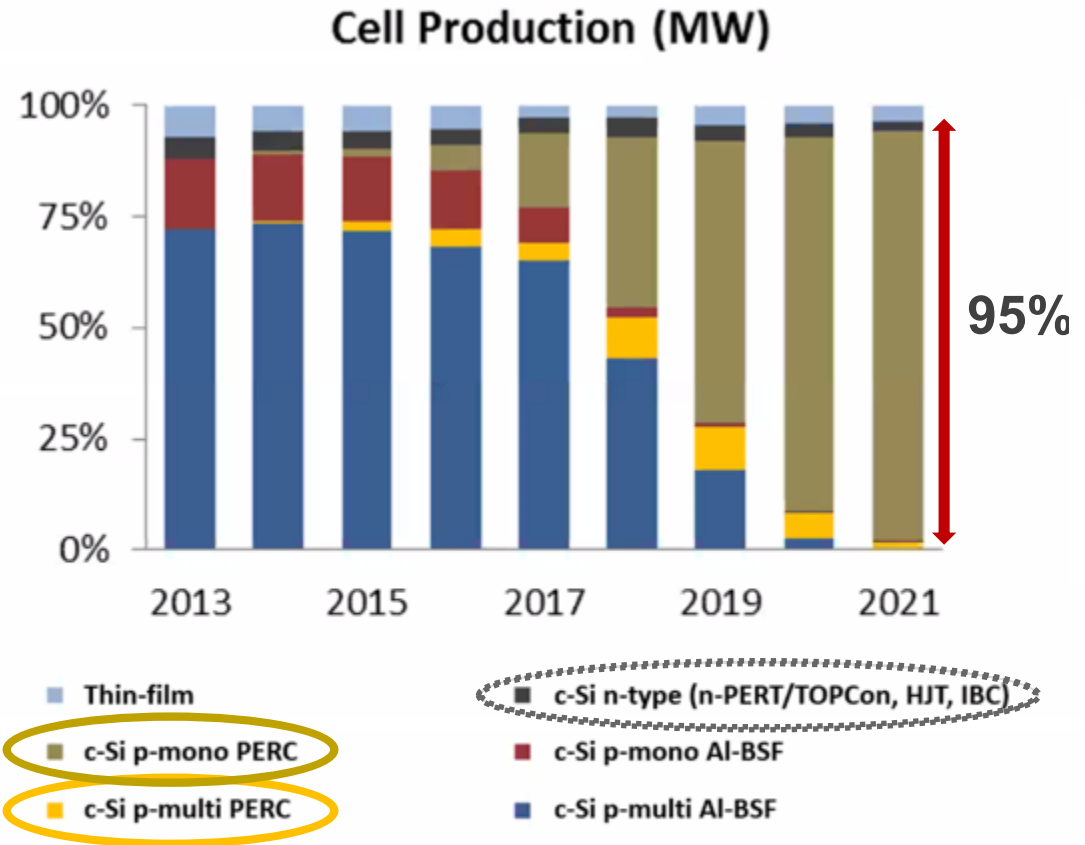
CO₂ emissions (Gt CO₂/yr)



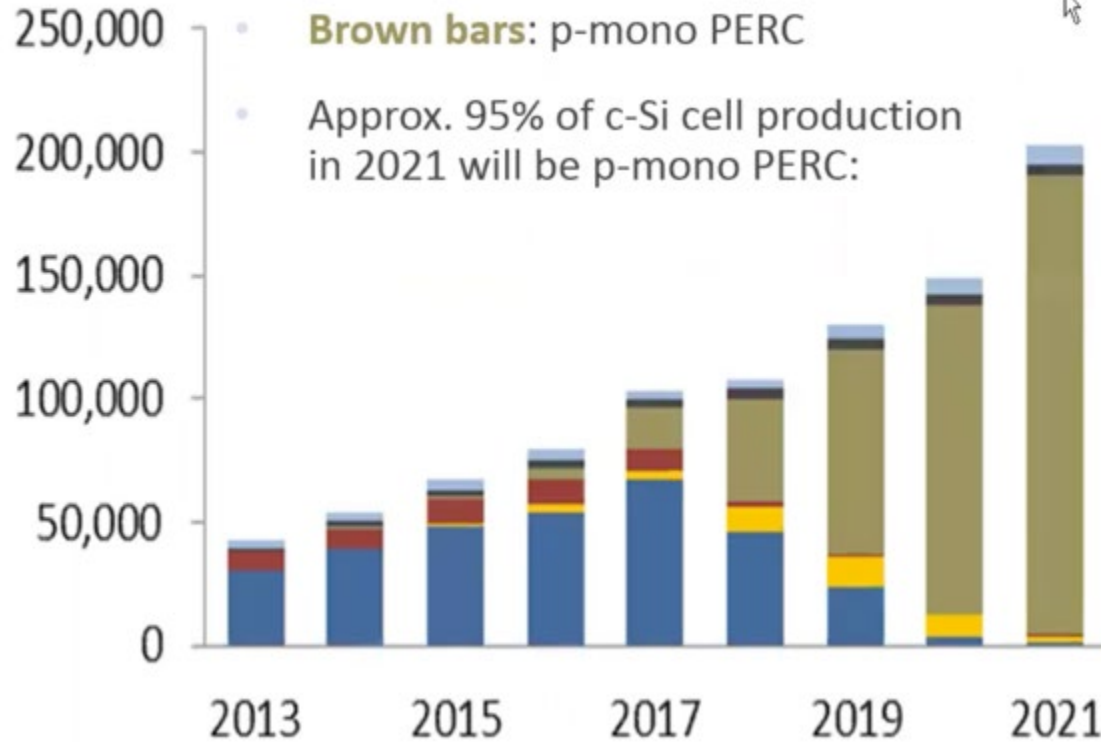
Part 2: PERC takes over the industry



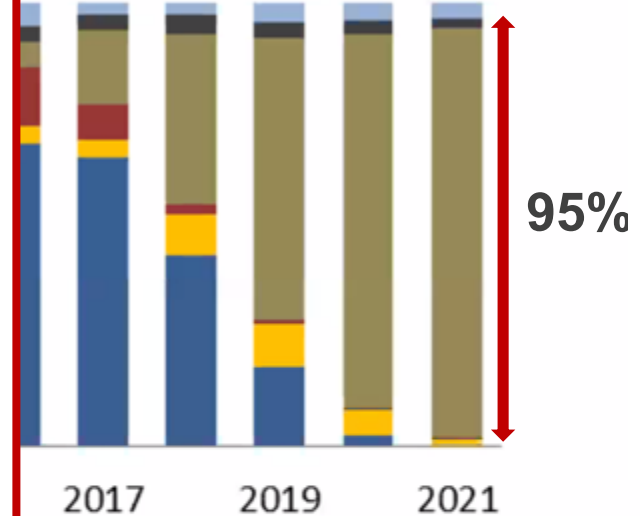
UNSW PERC rules!



Production (MW)

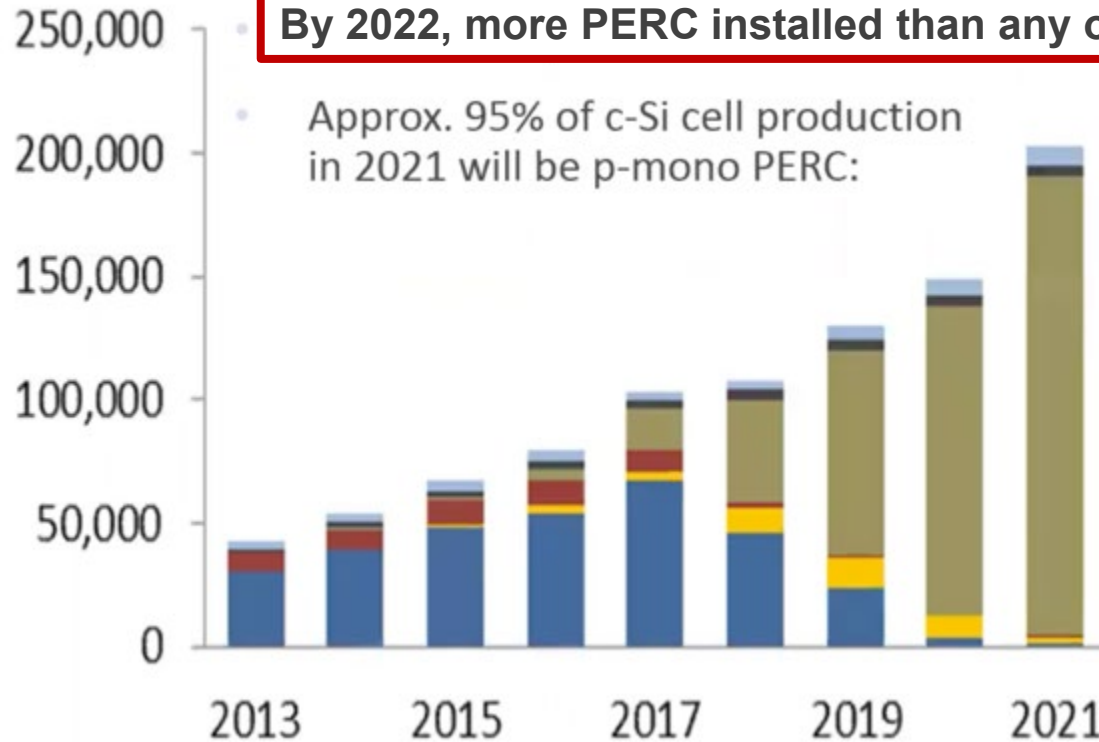


Production (MW)

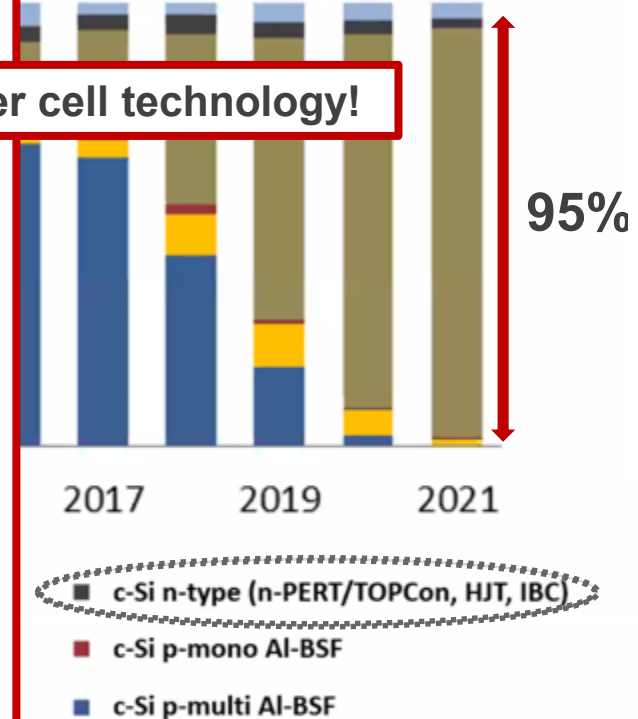


- c-Si n-type (n-PERT/TOPCon, HJT, IBC)
- c-Si p-mono Al-BSF
- c-Si p-multi Al-BSF

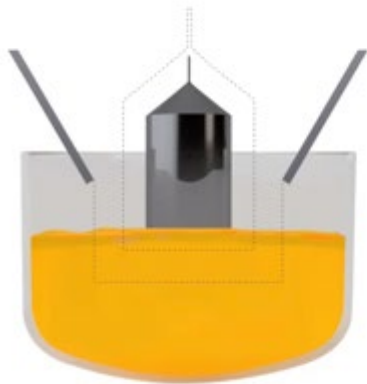
Production (MW)



Production (MW)



Process Optimization of Ingot Pulling Technology



Continuous increase of feeding rate

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



High speed ingot pulling technology

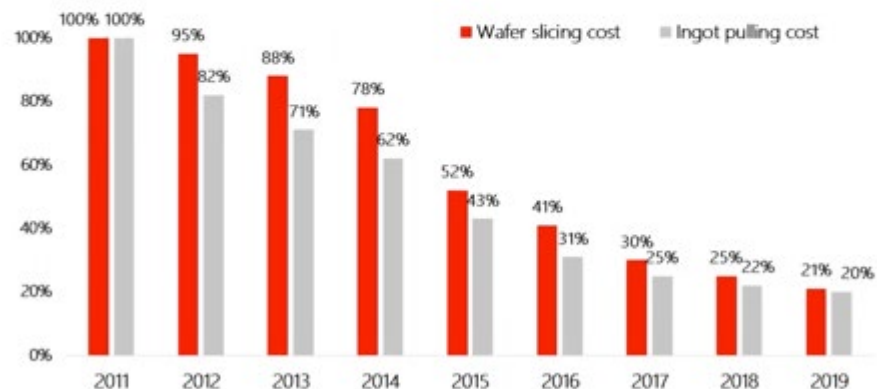
- Pulling speed increased 80%+ since 2013

Production line automation

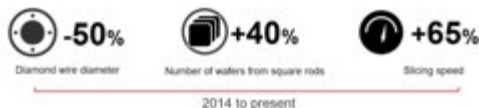
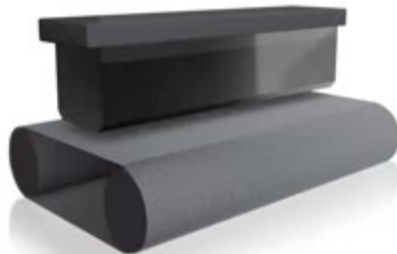
- Automatic control system
- Automatic loading technology
- Automatic edge cleaning system

Mono Wafer Cost Reduction

Mass Production Cost Down



- In 2014, LONGi took the lead in using diamond wire slicing technology in the production of photovoltaic silicon wafers and achieved 100% diamond wire slicing in 2015.
- Continuous reduction of diamond wire diameter reduces kerf loss during slicing process.
- High-speed slicing significantly improves the production efficiency of silicon wafer.



PERC offers new functionalities: Cheap bifacial cells!

The image features a large-scale solar farm in the background with rows of solar panels mounted on metal structures. In the foreground on the right, three individual bifacial solar panels are shown, highlighting their dark blue, grid-patterned surface. The panels are arranged in a slightly overlapping manner, with one panel in front of the other two.

LONGI SOLAR

435-455W BIFACIAL PERC SOLAR PANEL

Front 455W, Back 342W

Bifacial power output, one facial cost

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

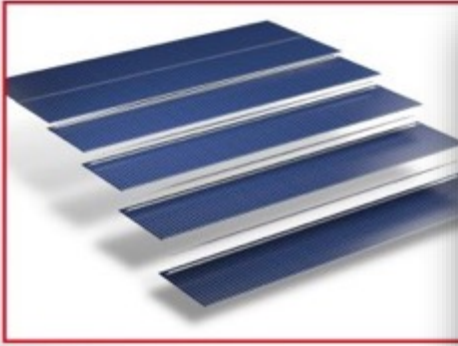


Honda Dream 1996



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

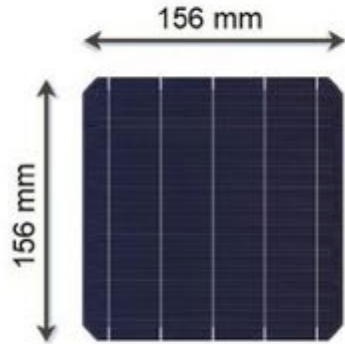
Honda Dream 1996



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

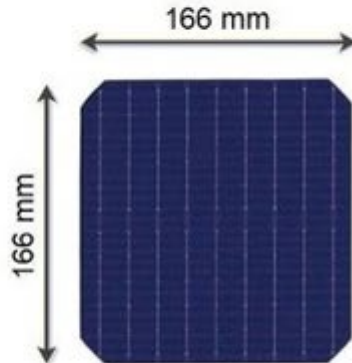


New Solar PV Cell Sizes



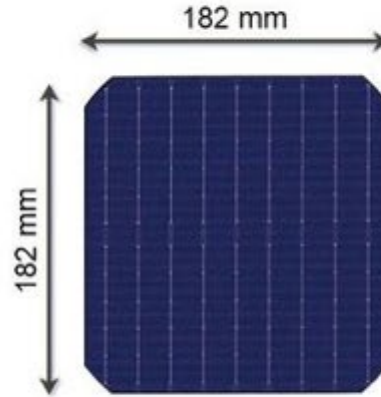
156 mm

Introduced 2012



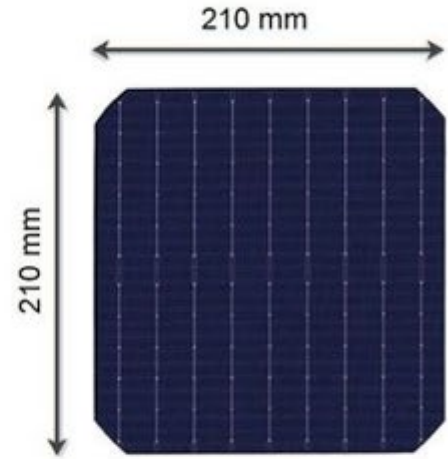
166 mm

New cell size 2019



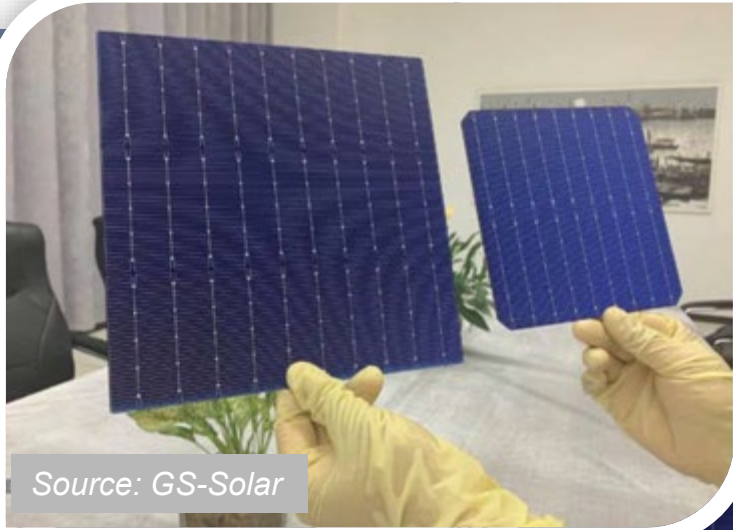
180 - 182 mm

————— New cell sizes in 2020 —————



210 mm

PFRC · Cheap bifacial cells! Half-cut cells, shingling



Source: GS-Solar



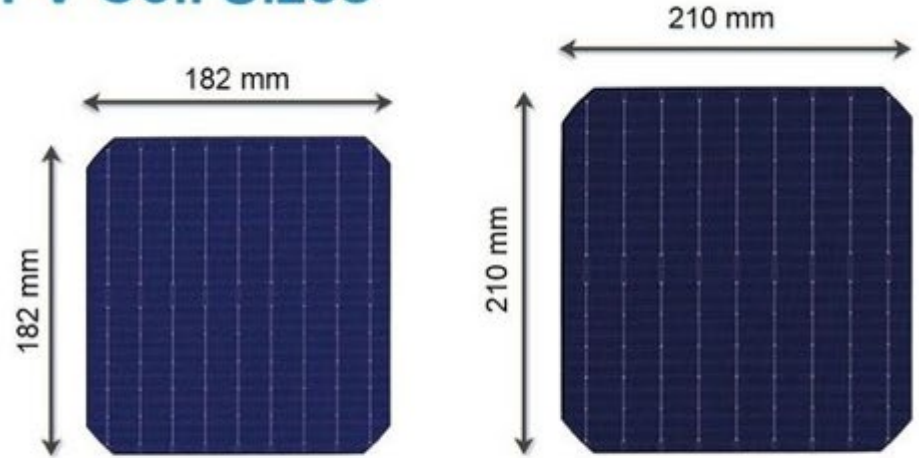
156 mm

166 mm

Introduced 2012

New cell size 2019

Solar PV Cell Sizes

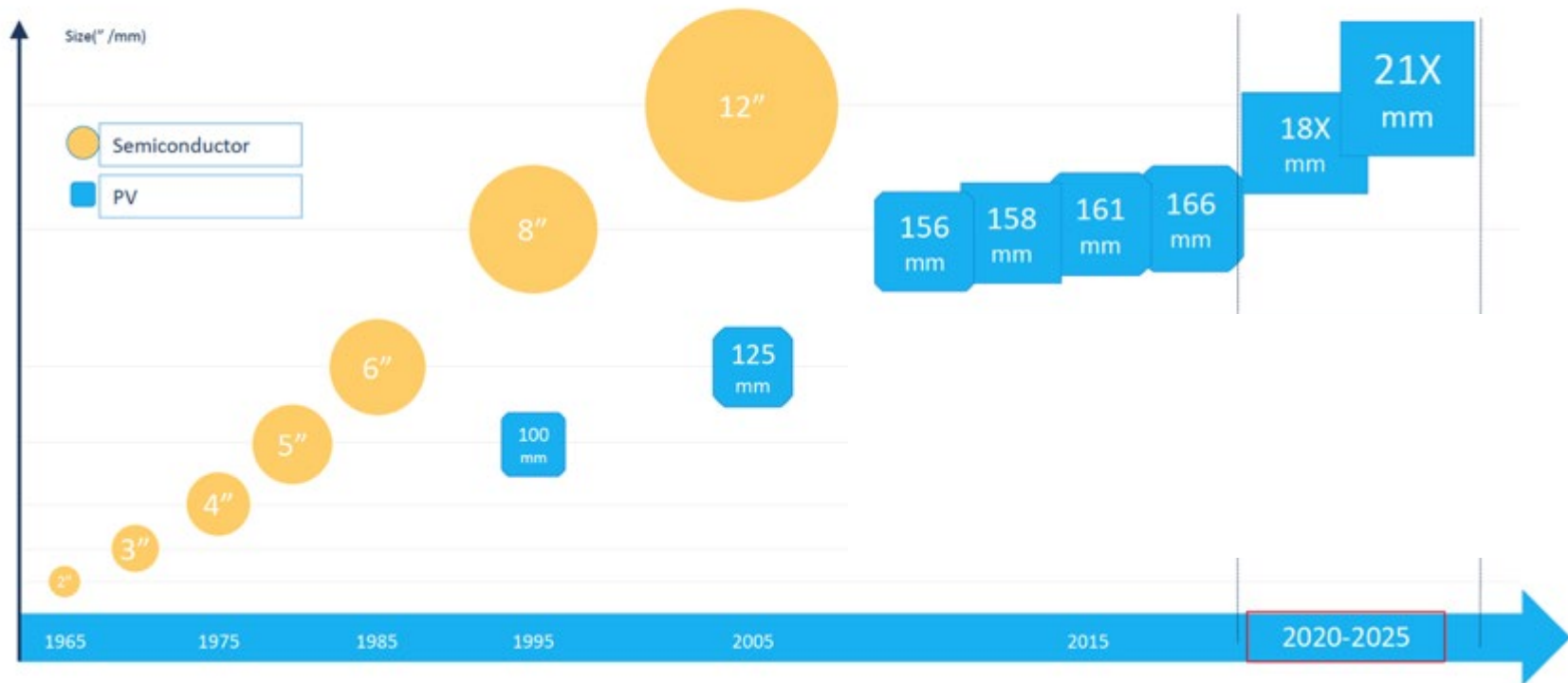


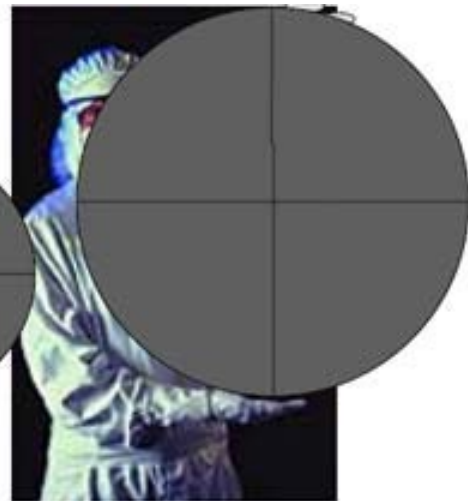
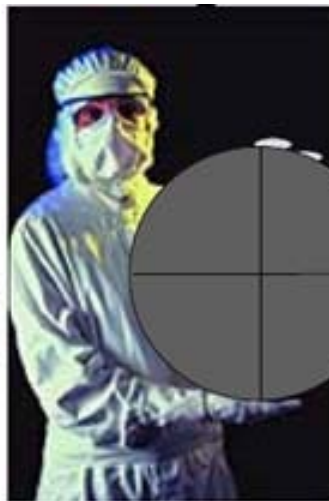
180 - 182 mm

210 mm

New cell sizes in 2020

Size trend of silicon wafer in semiconductor and PV industry





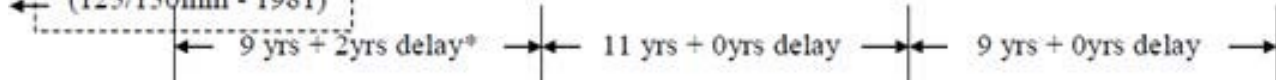
200mm/1990

300mm/2001

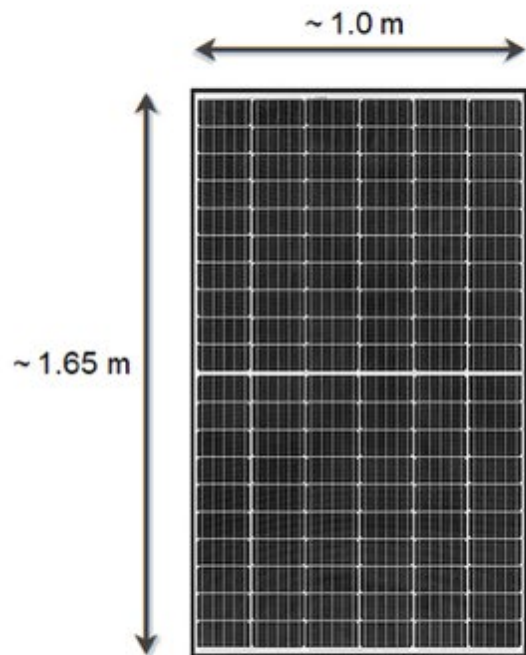
450mm/2012

675mm/2019?

← (125/150mm - 1981) →

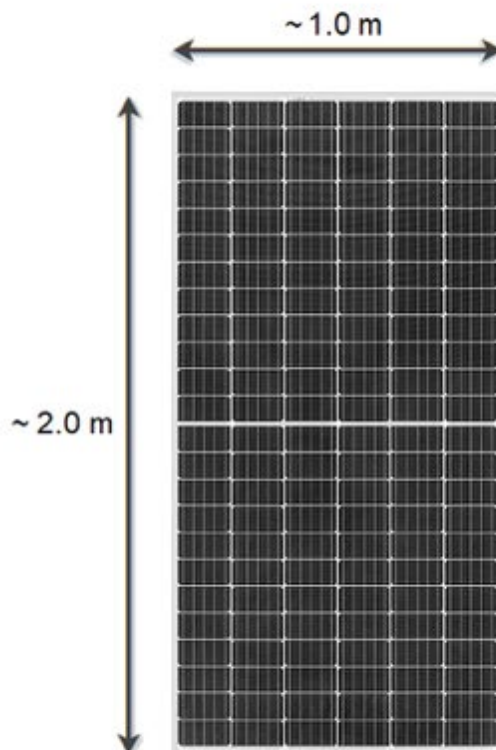


Solar Panel Size Vs Power Output



60 cells (120 HC)

300W - 380W



72 cells (144 HC)

350W - 450W



78 cells (156 HC*)

450W - 600W+

TRINA VERTEX FAMILY

Trina solar Vertex series
Cover all application scenario
Including Residential, C&I and Utility, etc.



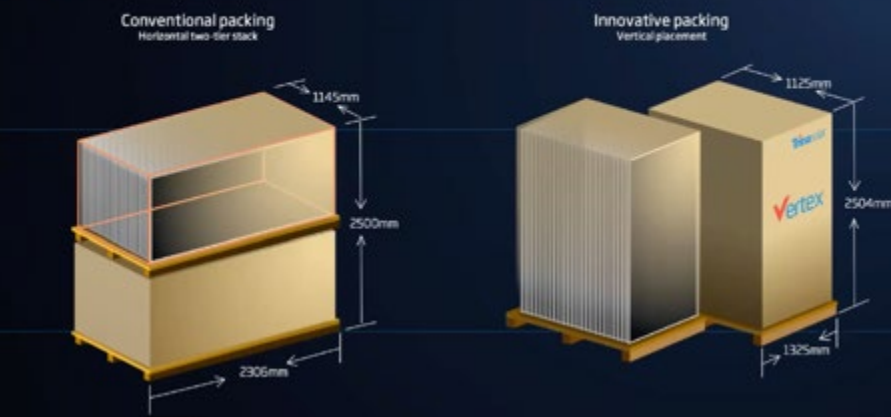
EQUIPMENT-AIDED INSTALLATION MODEL

IMPROVE INSTALLATION EFFICIENCY



INNOVATIVE PACKAGING CONCEPT

Maximizing the space utilization of containers, 12% saving in transportation costs comparing to the traditional packing.



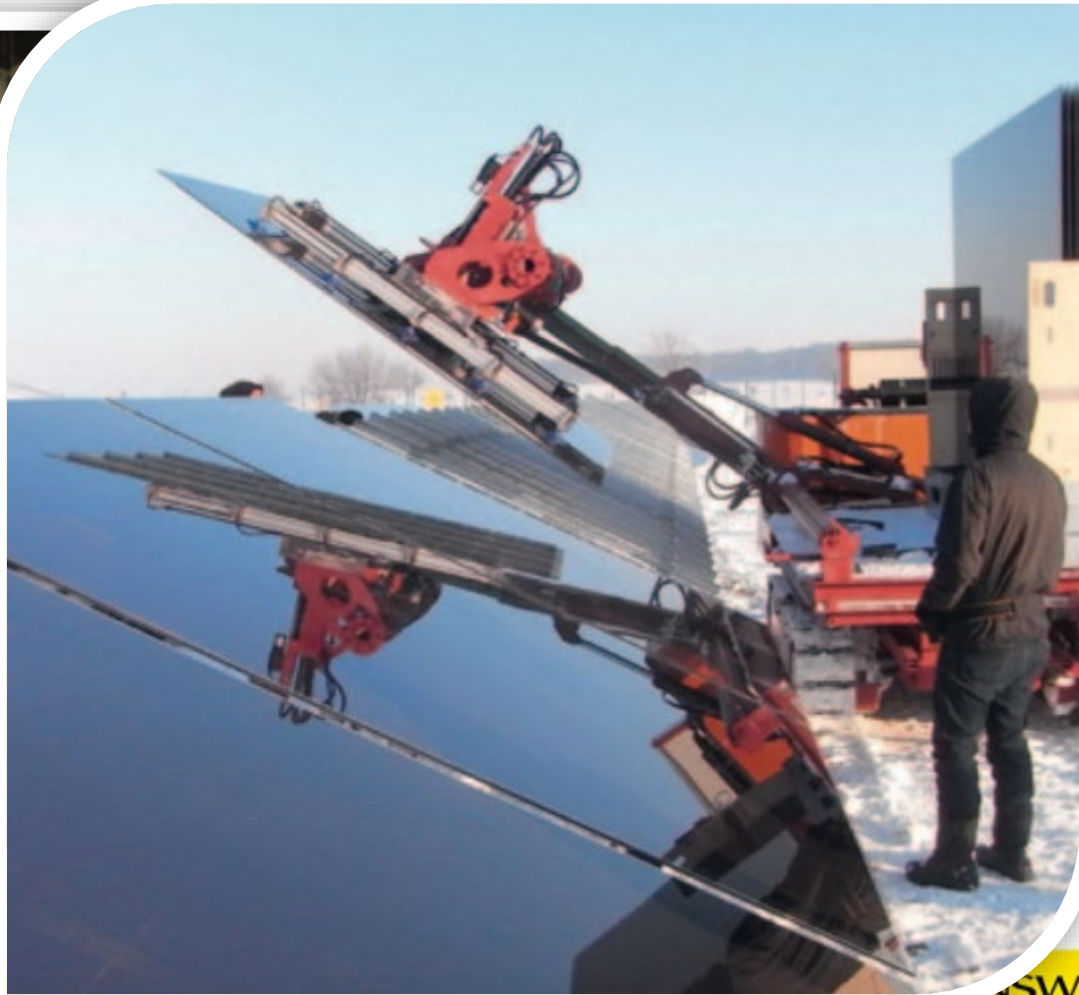
INNOVATIVE PACKAGING CONCEPT

SPACE LOADING CAPACITY PER CONTAINER
+12%



Category	Module Power	Piece per Pallet	Pallet NO. per Container	Power per Container
Other Module	540W	31	20	334.800W
Vertex Module	670W	31	18	373860W +39060W (+12%)





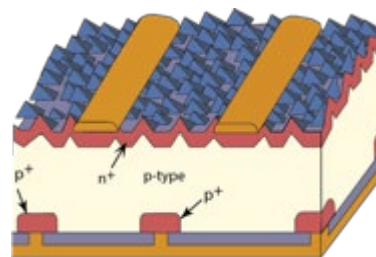
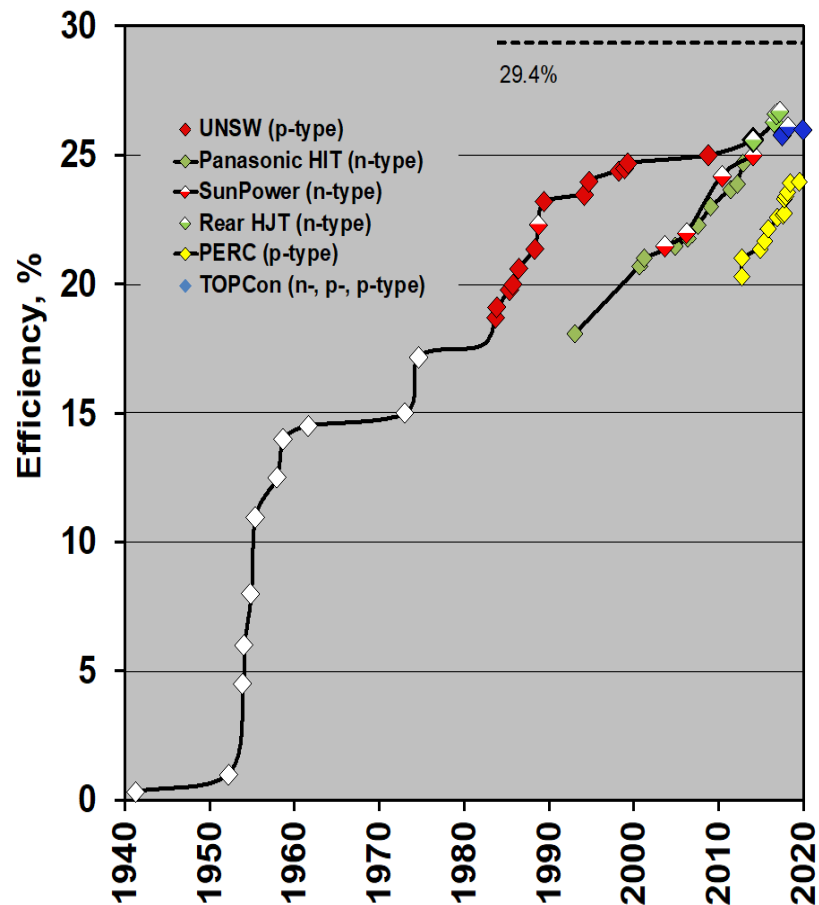


18m L

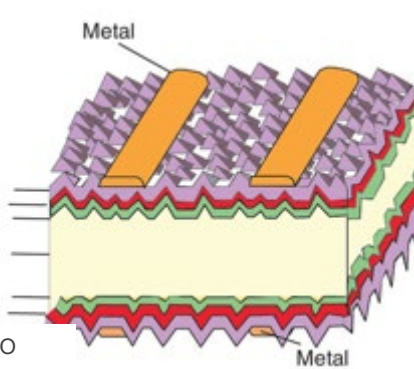
Part 3: What comes after PERC?



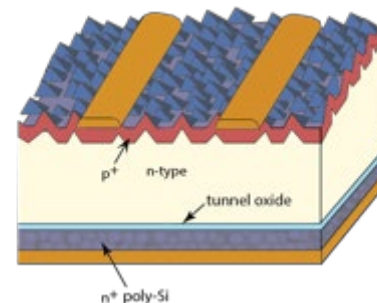
Contending technologies



PERC, n-PERT

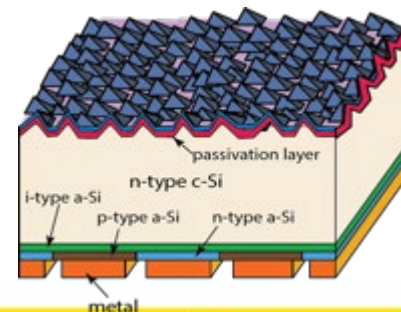


TOPCon

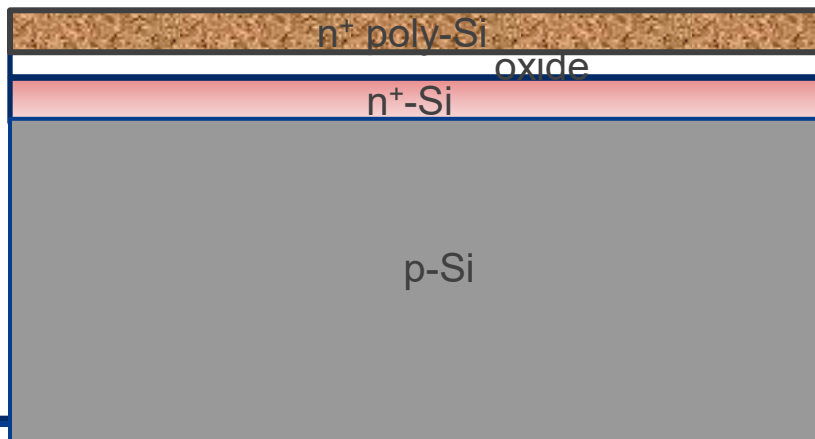


HJT

IBC



UNSW reported first TOPCon solar cell (1983)



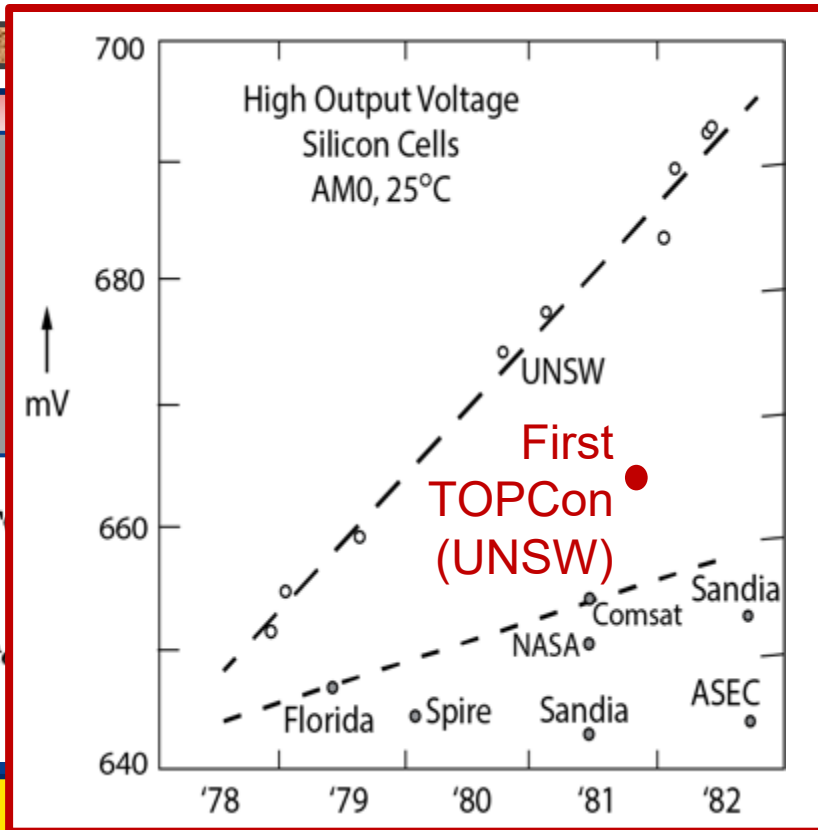
Solar Cells, 8 (1983) 3 - 16

ADVANTAGES OF METAL-INSULATOR-SEMICONDUCTOR STRUCTURES FOR SILICON SOLAR CELLS

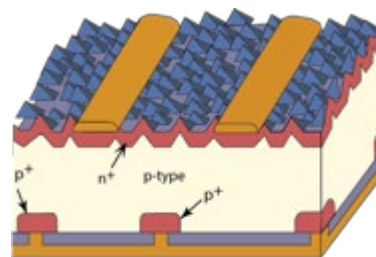
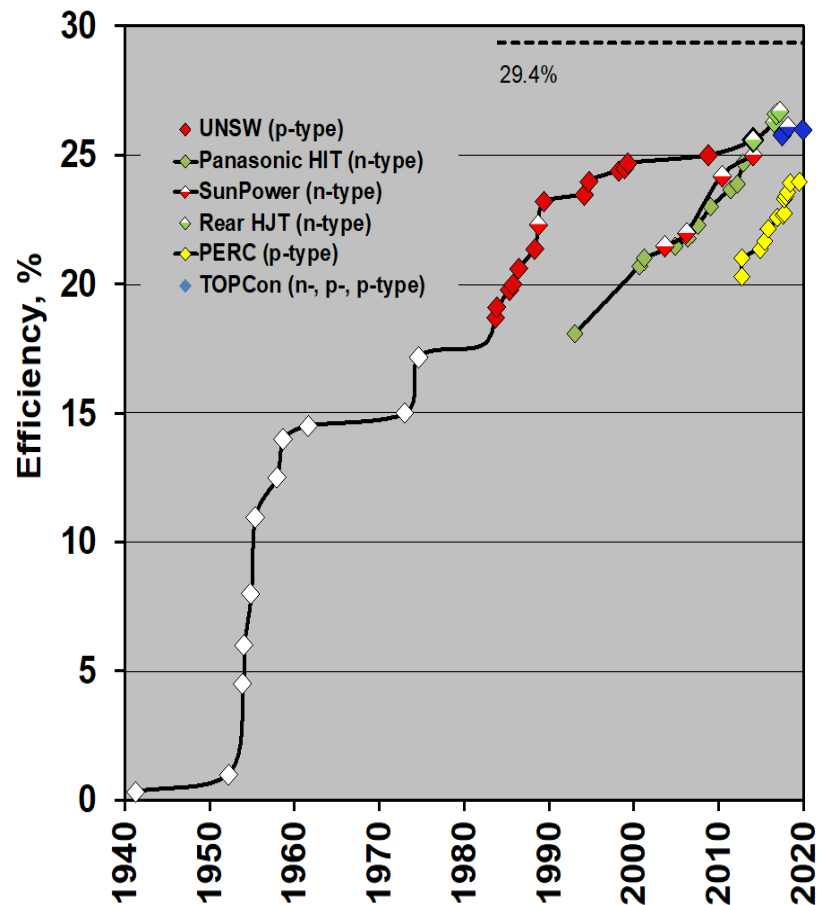
M. A. GREEN and A. W. BLAKERS

Solar Photovoltaic Laboratory, University of New South Wales, Kensington (Australia)

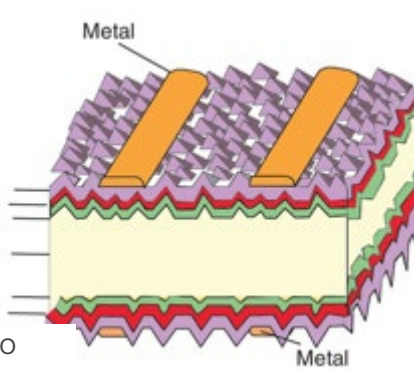
(Received January 26, 1982; accepted April 5, 1982)



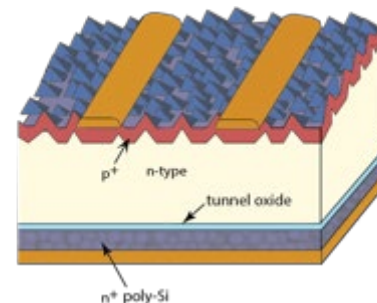
Contending technologies



PERC, n-PERT

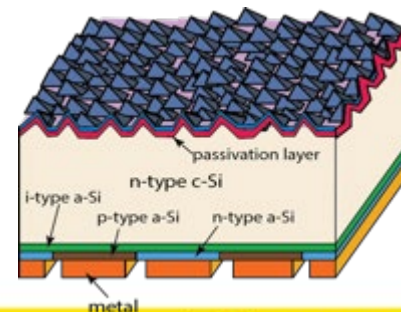


TOPCon

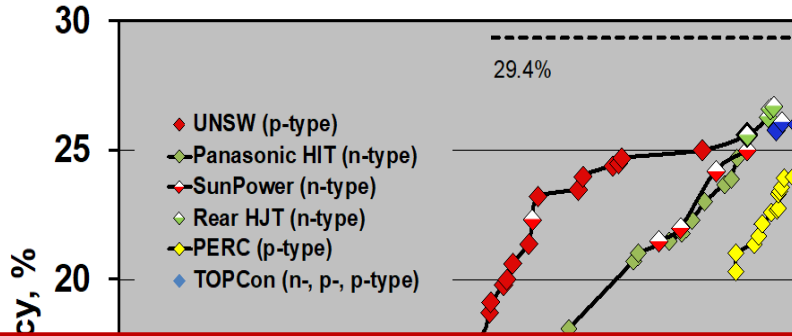


HJT

IBC



Shift to n-type wafers?

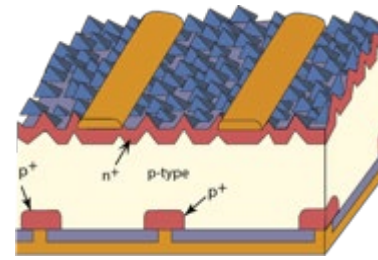
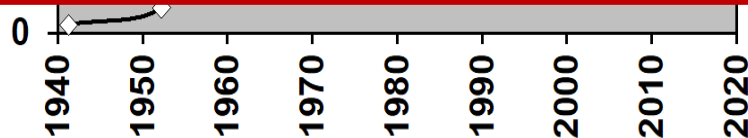


Advantage

n-type CZ wafers can be better quality

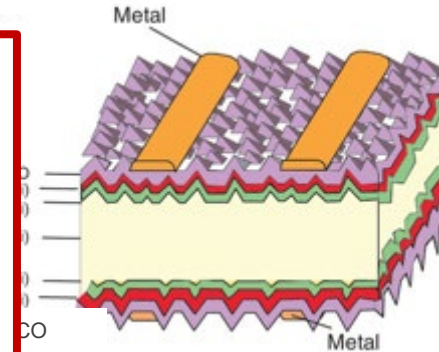
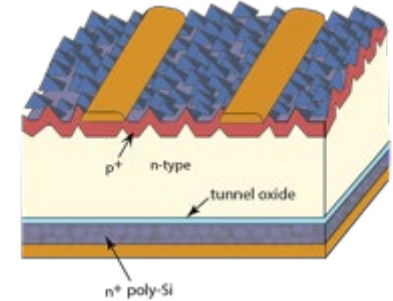
Gives:

- . higher efficiency
- . lower temperature coefficients
- . better bifacial response



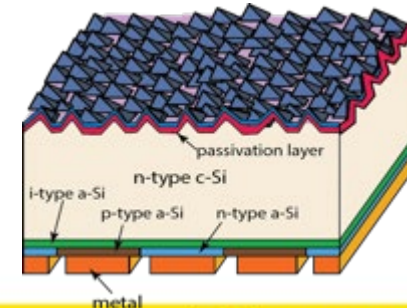
PERC, n-PERT

TOPCon

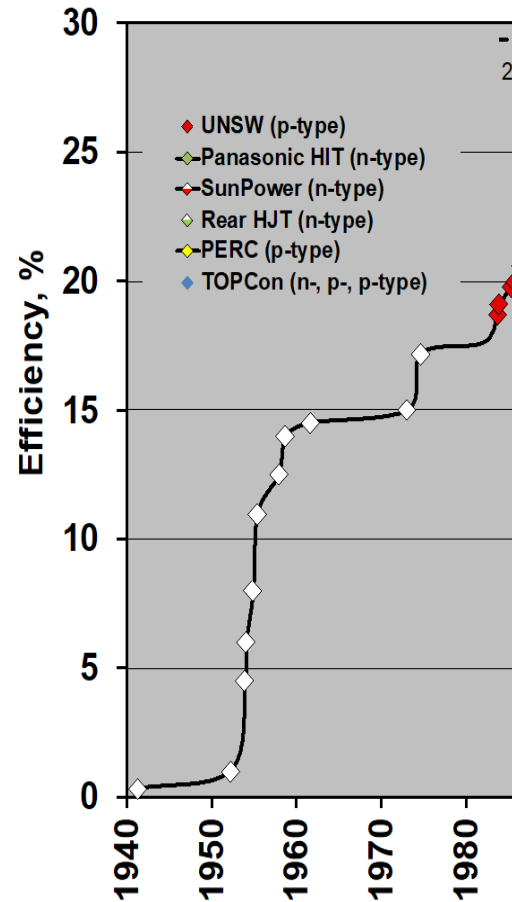


HJT

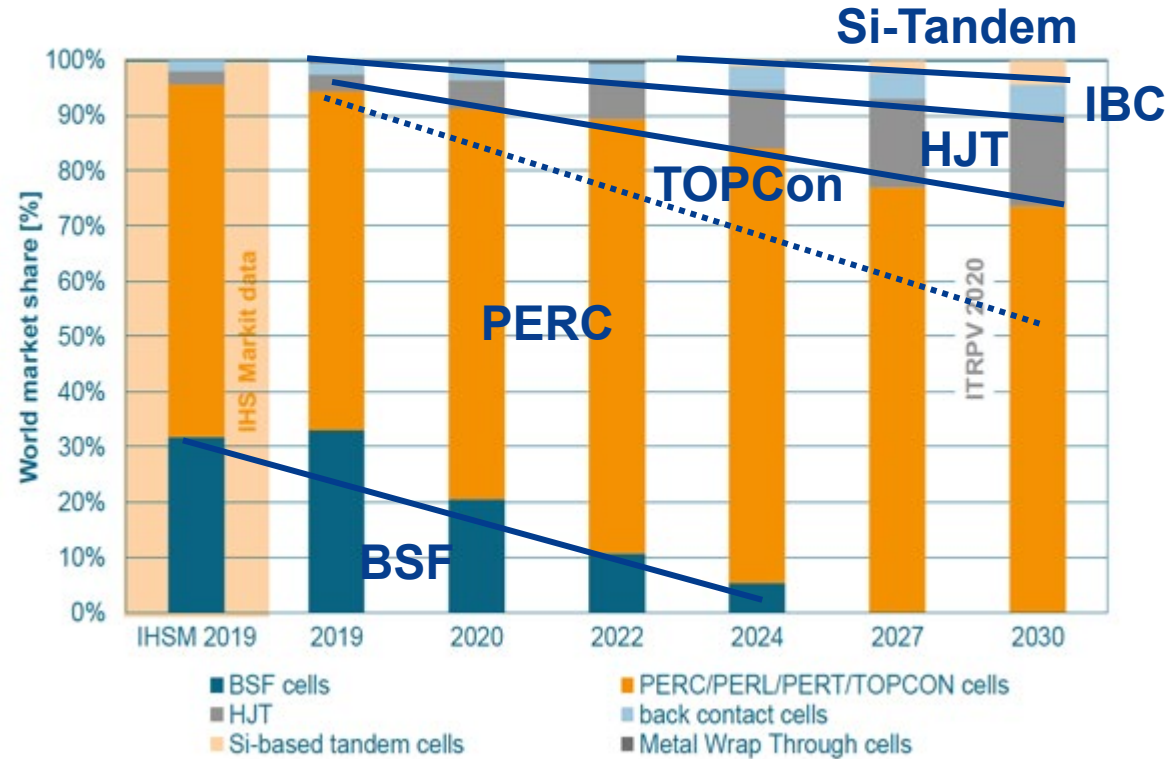
IBC



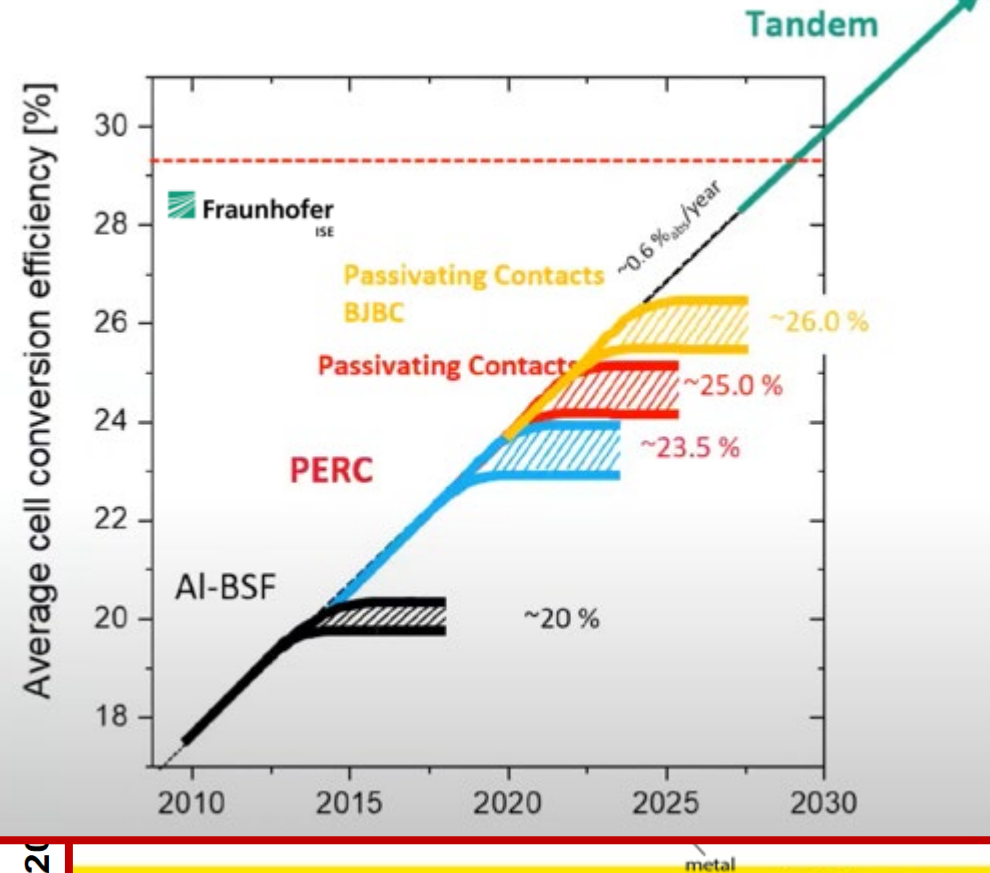
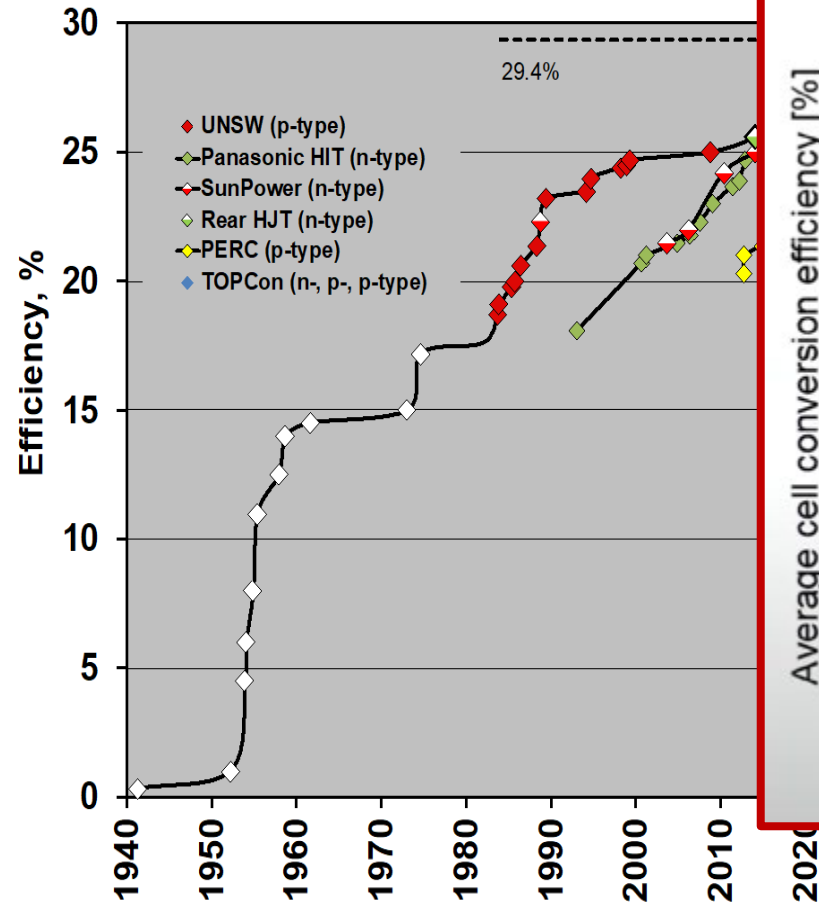
Shift to n-type wafers?



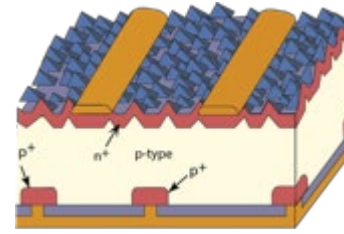
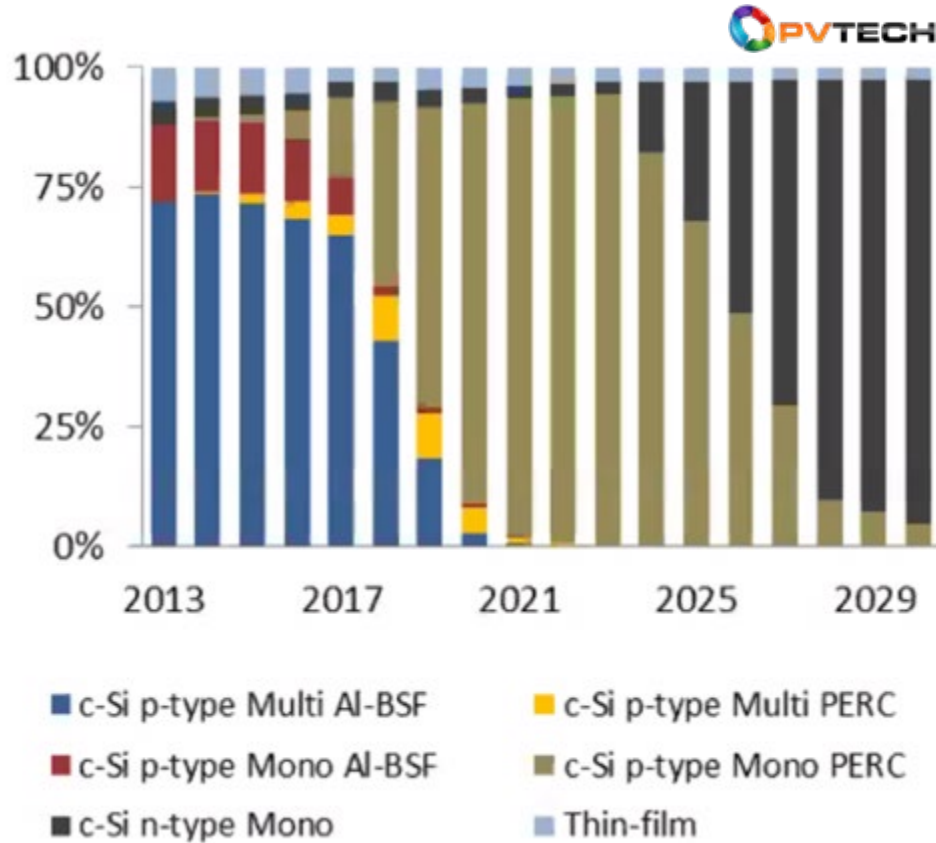
Different cell technology



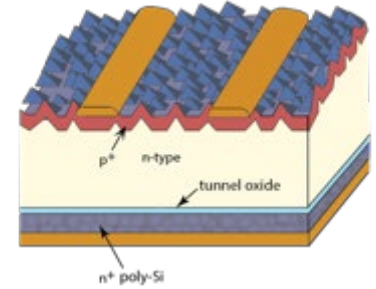
Shift to n-type wafers?



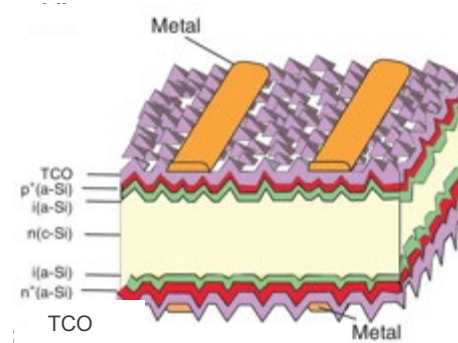
Shift to n-type wafers?



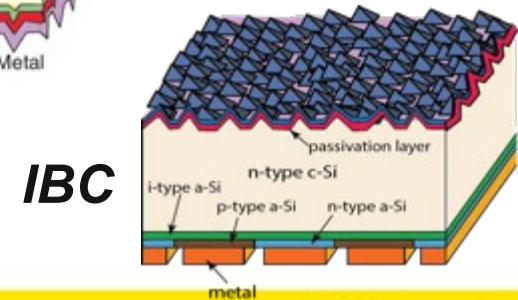
PERC, n-PERT



TOPCon



SHJ

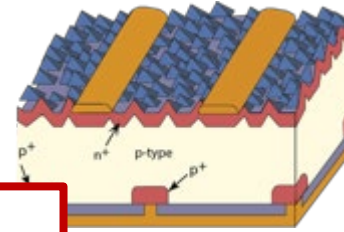
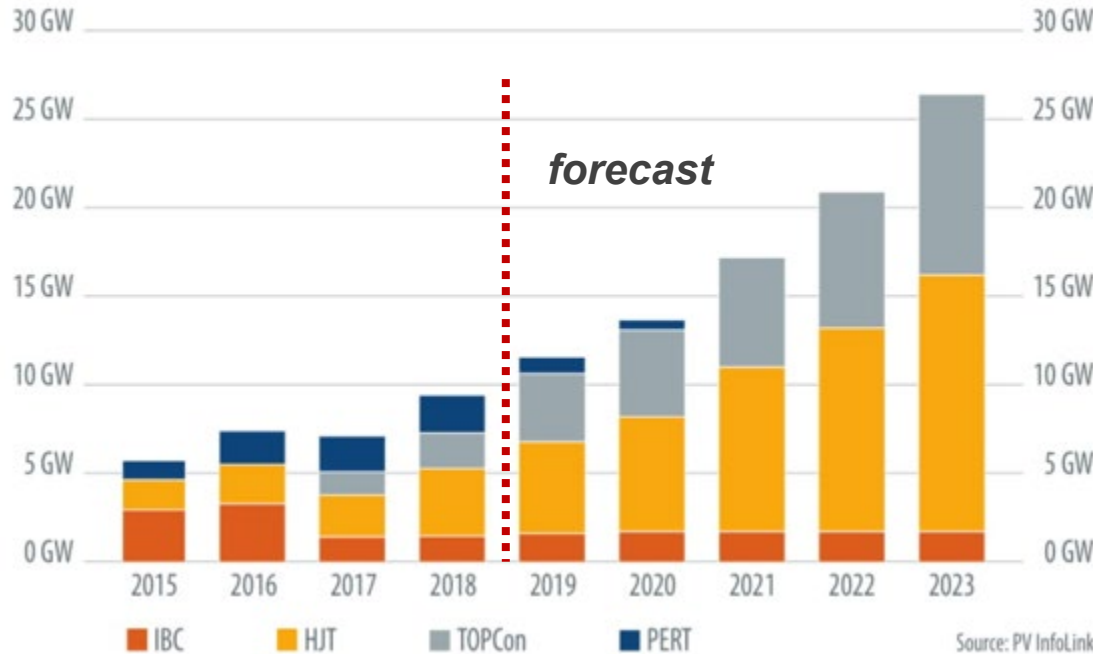


IBC

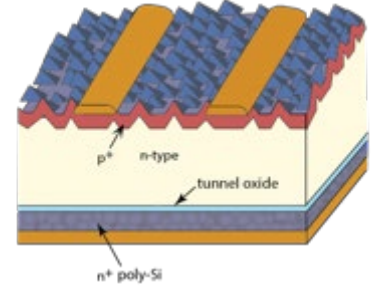
What comes after PERC?

Switch to n-type wafers??

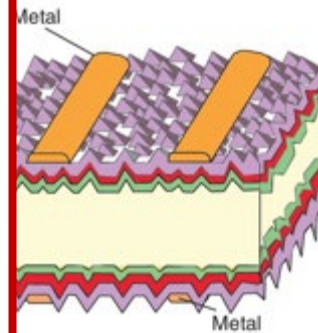
Capacity forecast of N-type technology



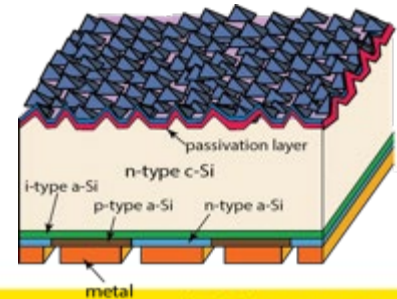
PERC, n-PERT



TOPCon



SHJ



IBC

WH
Sw

Capacity for

30 GW

25 GW

20 GW

15 GW

10 GW

5 GW

0 GW

IBC

HJT

TOPCon

PERT

2015

2016

2017

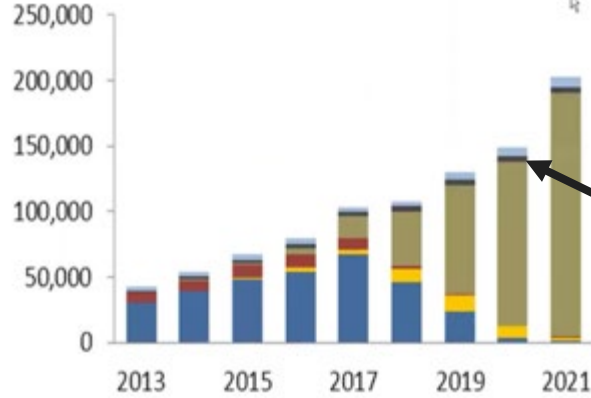
2018

2019

2020

2021

Production (MW)



?

n-type Production by Cell Type

GW

10.0

8.0

6.0

4.0

2.0

0.0

2013

2014

2015

2016

2017

2018

2019

2020

n-type
PERC &
TOPCon
n-type
HJT &
IBC

© PV-Tech, Solar Media Ltd, April 2020

Source: PV Manufacturing & Technology Quarterly report, April 2020 release.



Source: PV InfoLink

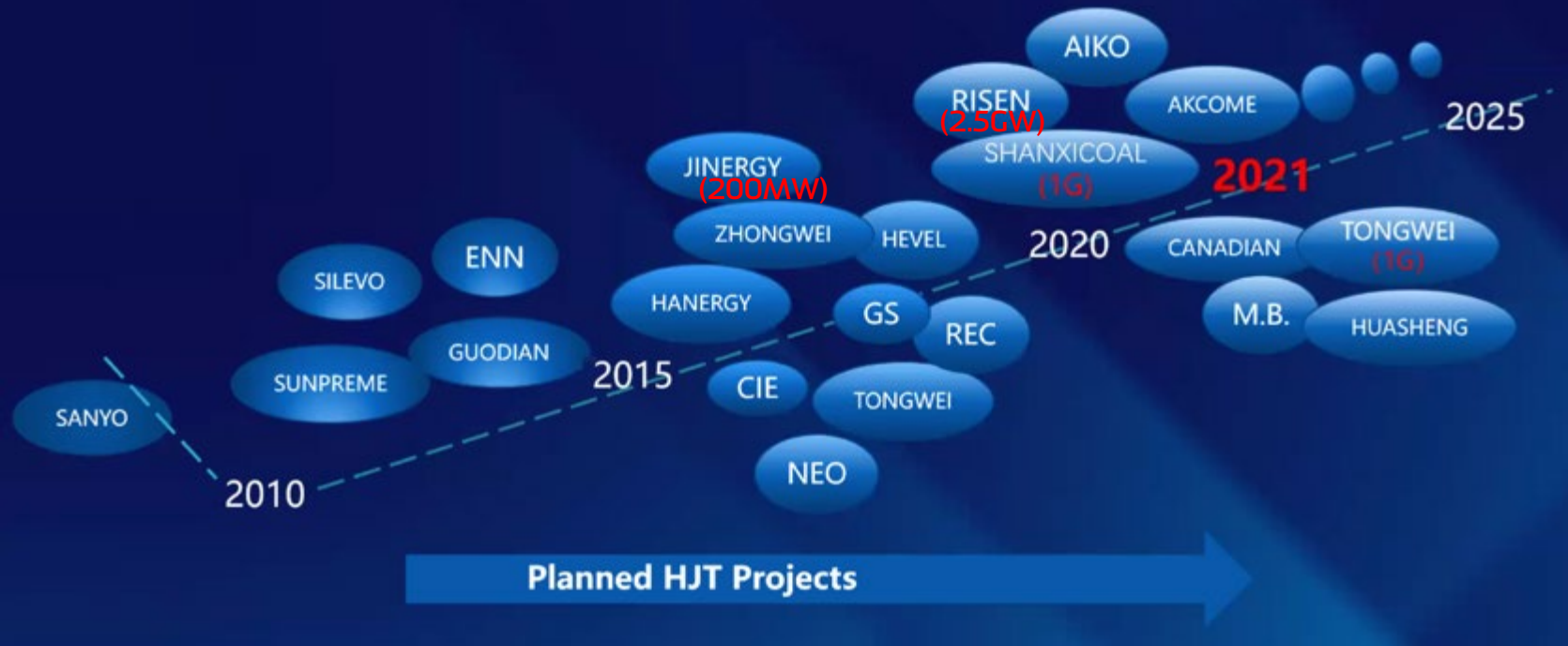


metal

Grass greener on other side?



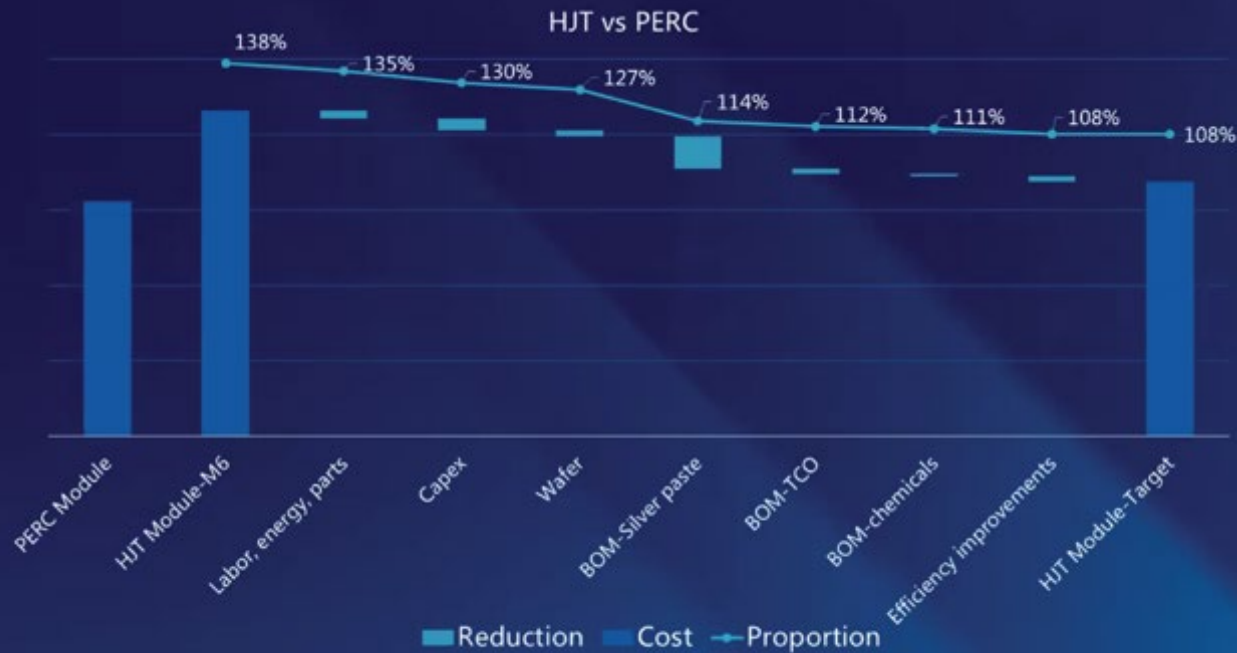
Background Information



Grass greener on other side?



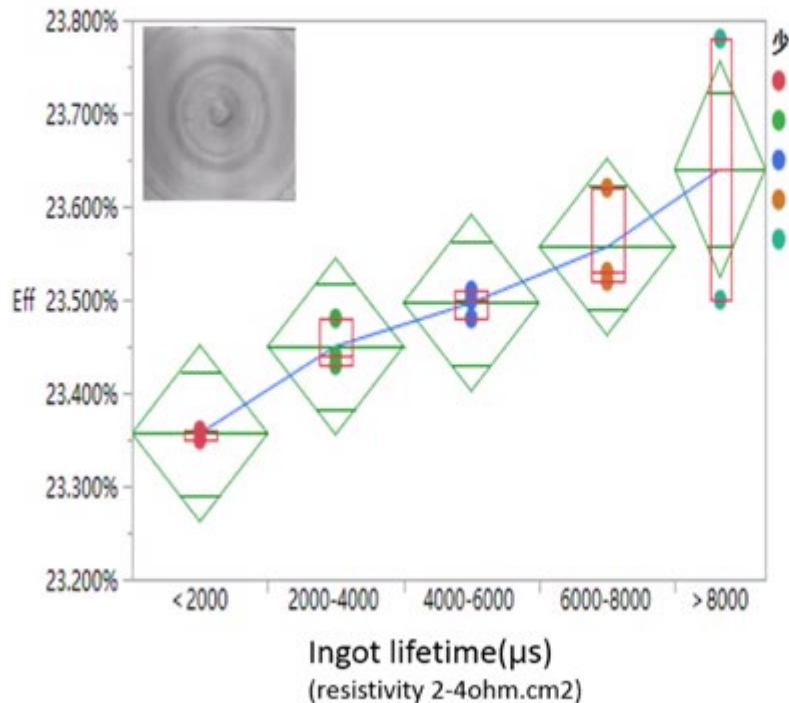
HJT Mass Production Cost



Grass greener on other side?

2、Problems from mass production line

1) Ingot's lifetime



- Long lifetime ingot represents good quality wafer, which brings high efficiency solar cell.
- Wafer quality should be controlled, even for N-type wafer



Grass greener on other side?

2、Problems from mass production line

1) Ingot's lifetime



PV Poly Silicon Weekly Spot Price

PVinsights

Item	High	Low	Average
PV Grade PolySilicon (9N/9N+)	17.400	10.500	15.630
2nd Grade PolySilicon (6N-8N)	9.500	8.000	8.470
N Mono Grade PolySilicon in China (12N/12N+)	17.400	17.050	17.240

Unit: USD/Kg

[more](#)

Last Update: 2021-03-17



Grass greener on other side?

2、Problems from mass production line

1) Ingot's lifetime



Eff

PERC
-170um



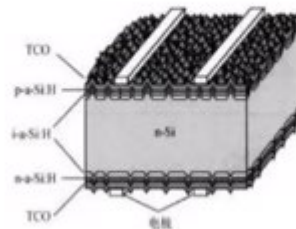
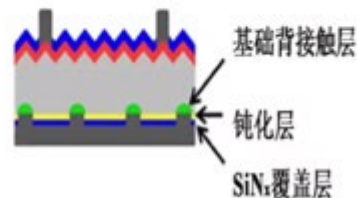
Tube furnace

HJT
<130um



In-line equipment

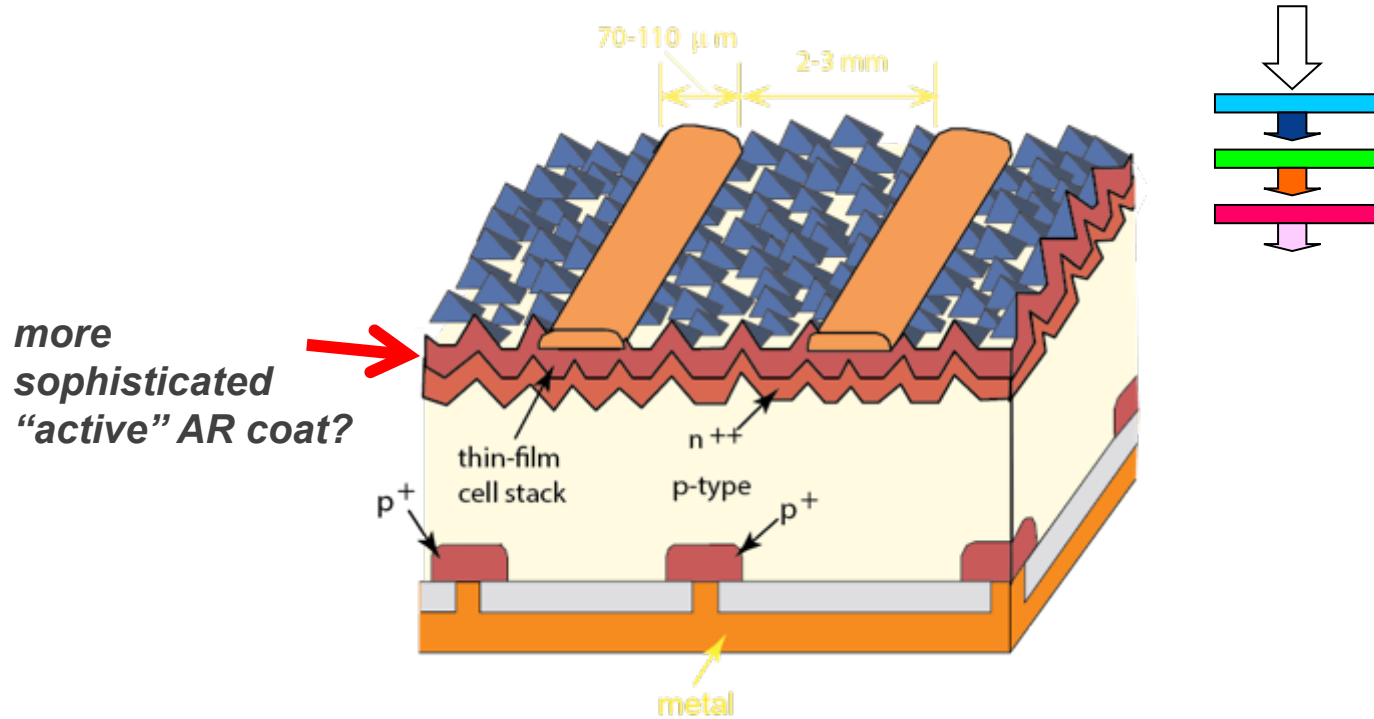
- For HJT, thinner wafer is more important for cost reduction



Part 4: What comes after PERC? (long term)

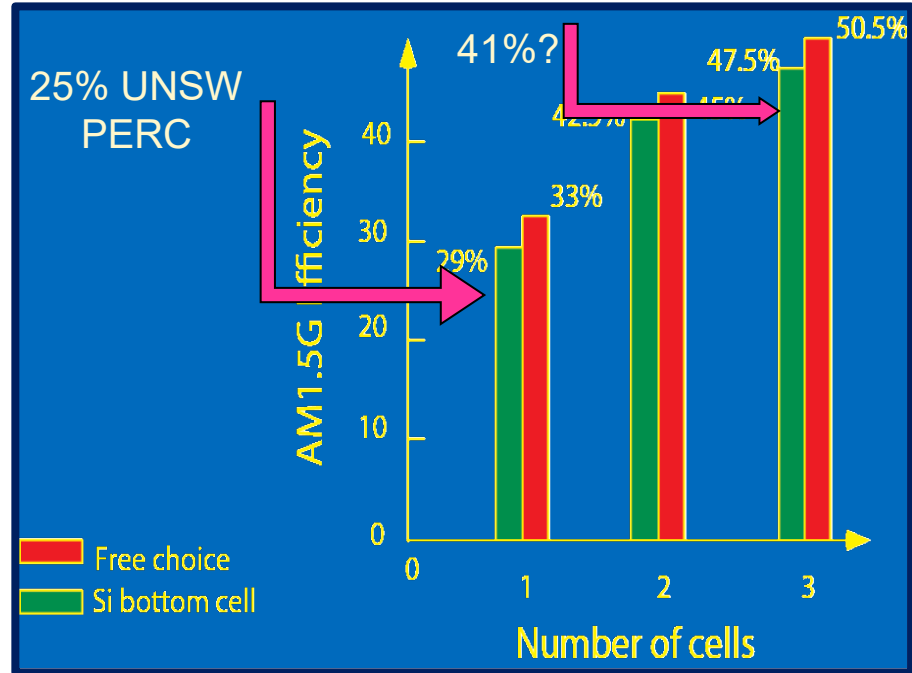
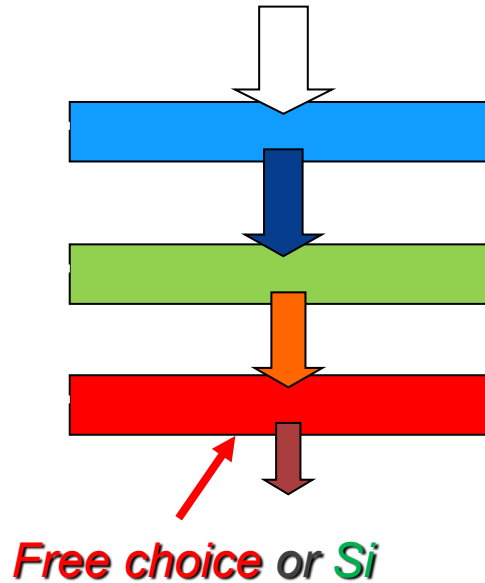


What comes after PERC? – longer term



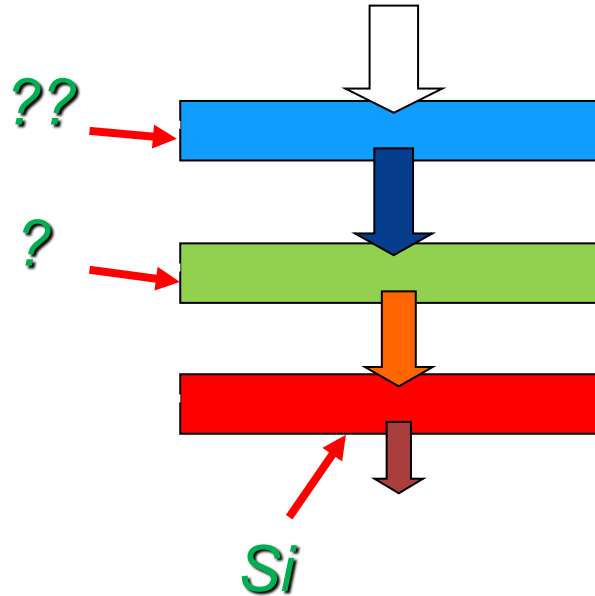
Supercharged tandem PERC?

What comes after PERC? – longer term

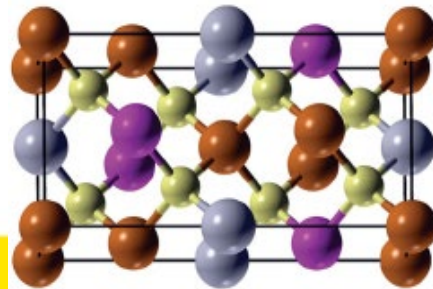


What comes after PERC? – longer term

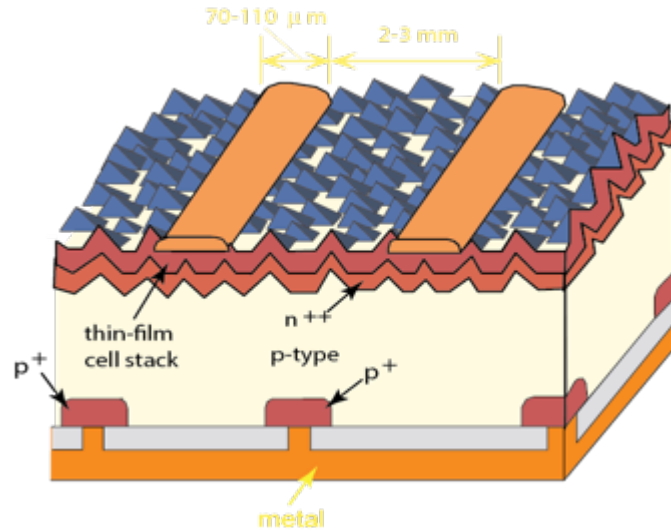
Like silicon, ? needs to be abundant, non-toxic, stable, efficient (>20%)



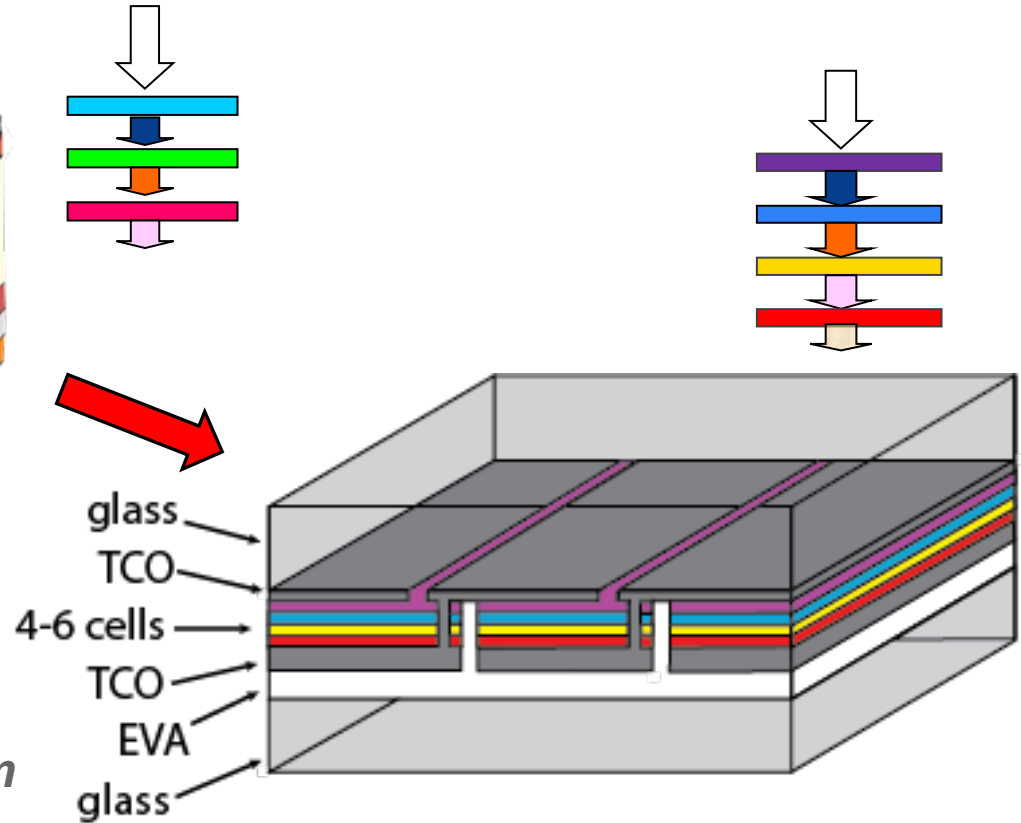
II-VI {	Perovskite	✓	✗	✗	✓
	Organics (OPV)	✓	✓	✗	✗
	$\text{Cu}_2\text{Zn}(\text{Sn}:\text{Si})\text{S}_4$	✓	✓	✓	✗
	$\text{Cu}(\text{In}:\text{Ga})(\text{S}:\text{Se})_2$	✗	?	✓	✗
	$(\text{Cd}:\text{Zn}:\text{Mg})(\text{Se}:\text{Te})$	✗	✗	✓	?
III-V	$(\text{Al}:\text{Ga}:\text{In})(\text{As}:\text{P})$	✗	?	✓	?



What then? – *the end for silicon?*



Si - 3 cell tandem



4-6 cell thin-film tandem

Part 5: Can solar power the world?

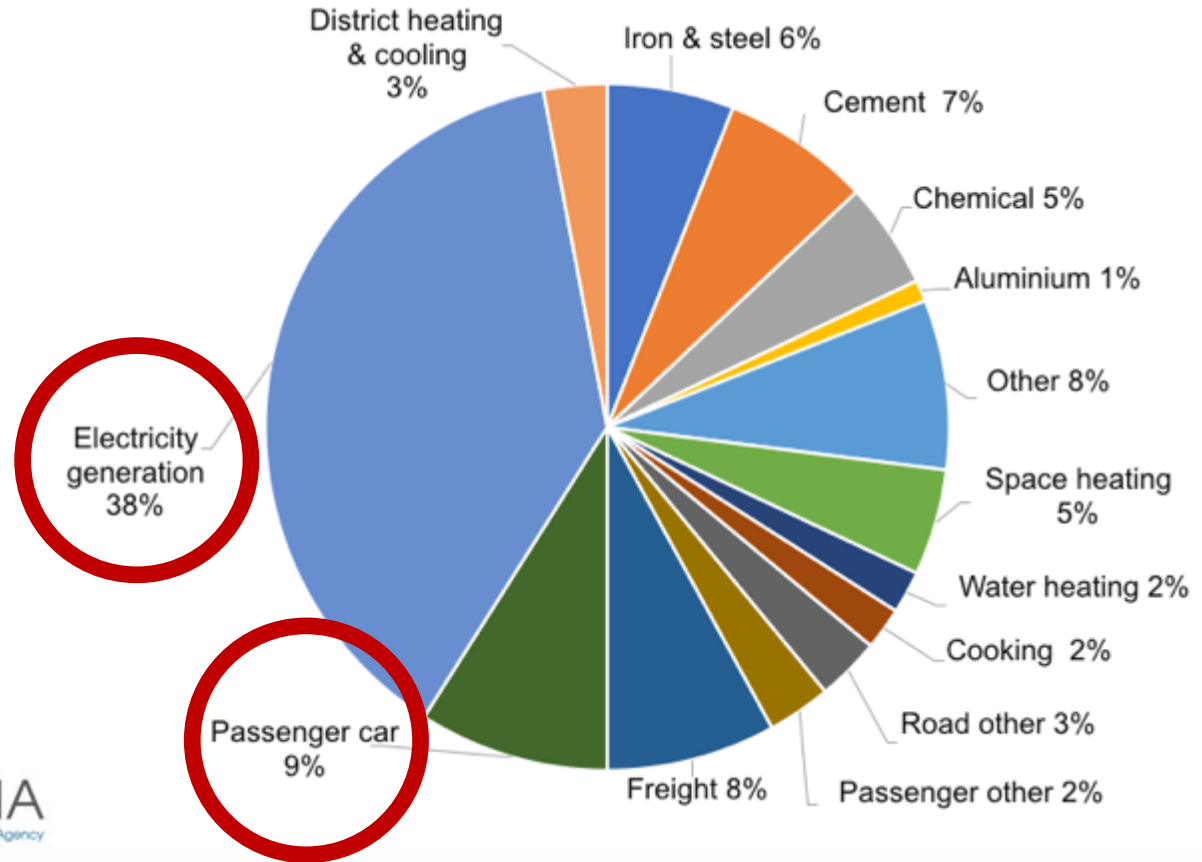


ARENA

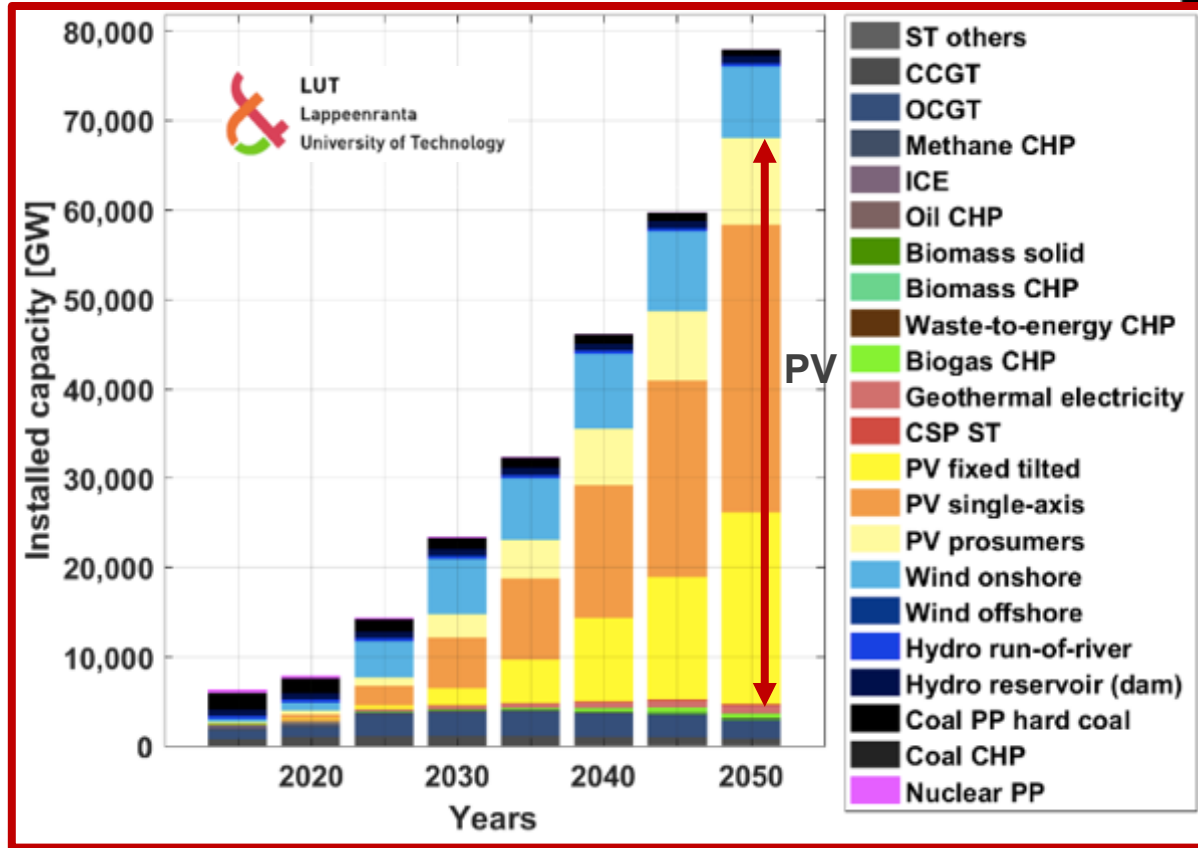
Australian Government
Australian Renewable Energy Agency

ACAP

Source of global CO₂ emissions



Recent studies suggest so!



APRIL 2019

Funded by DBU STIFTUNG MERCATOR

GLOBAL ENERGY SYSTEM BASED ON 100% RENEWABLE ENERGY

Power, Heat, Transport and Desalination Sectors



Study by

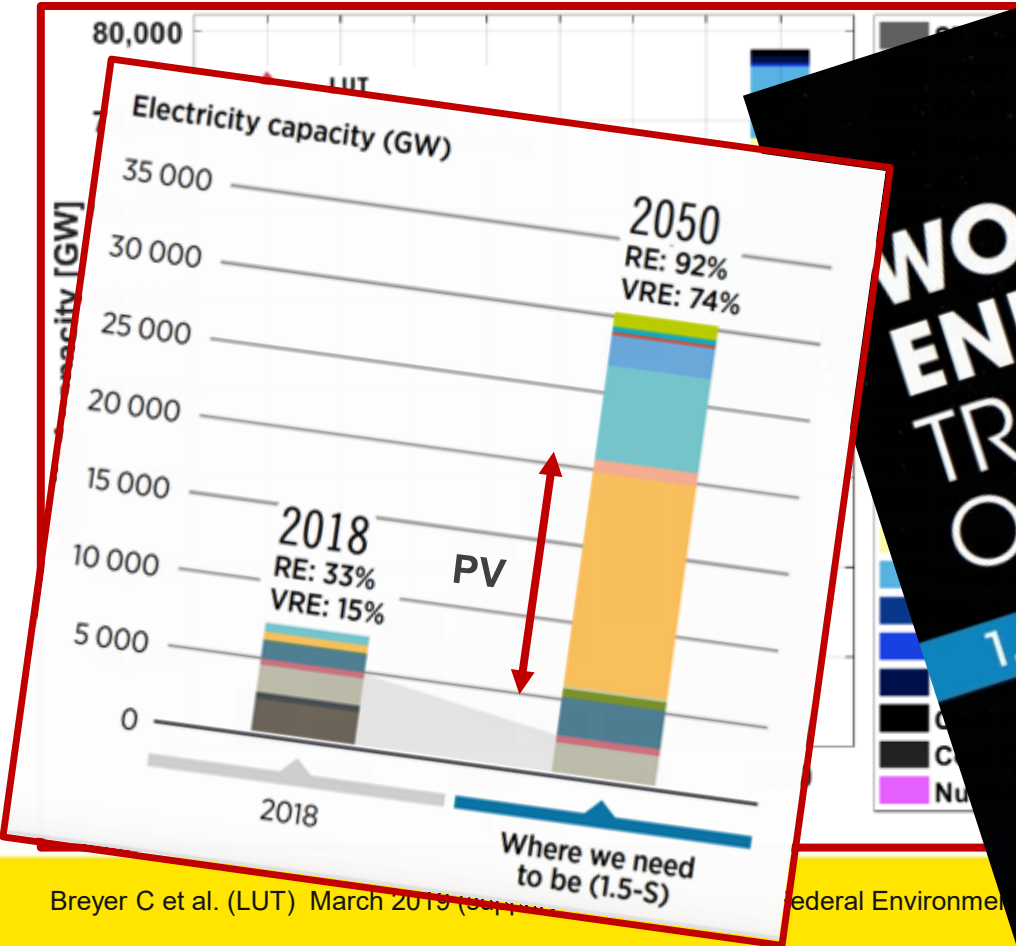


ENERGYWATCHGROUP

P.O. Box 20
FI-00051 Lappeenranta
Finland
Tel.: +358 40277194
Email: marshall@lut.fi

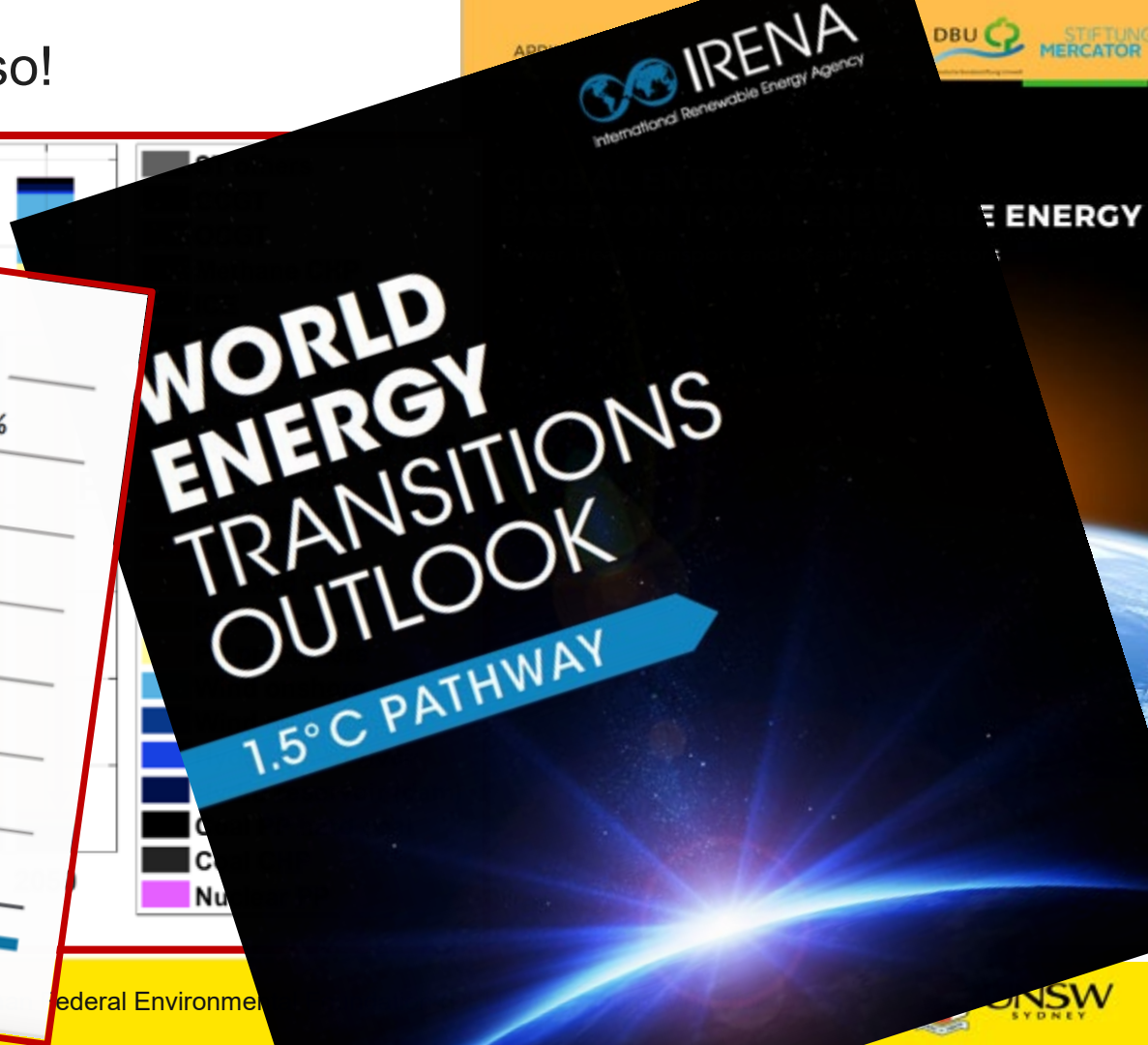
Albrechtstr. 22
10117 Berlin
Germany
Tel.: +49 30 809 988 80
Email: office@energywatchgroup.org

Recent studies suggest so!



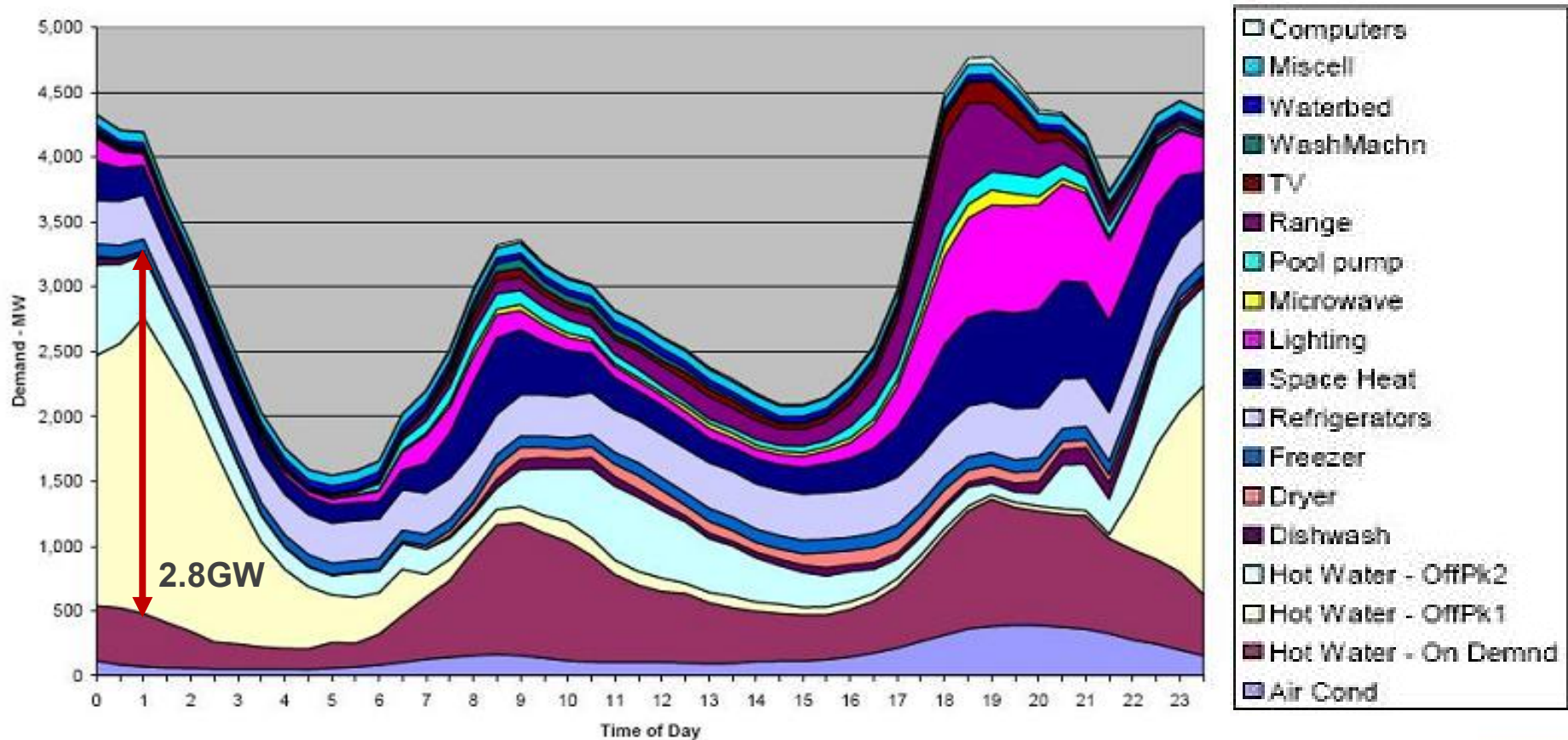
Breyer C et al. (LUT) March 2019 (GHI)

Federal Environment



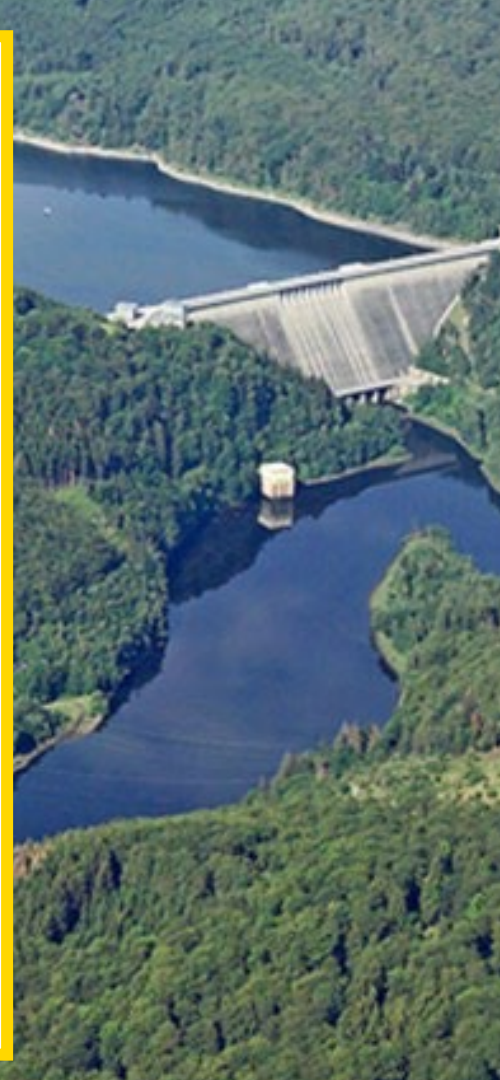
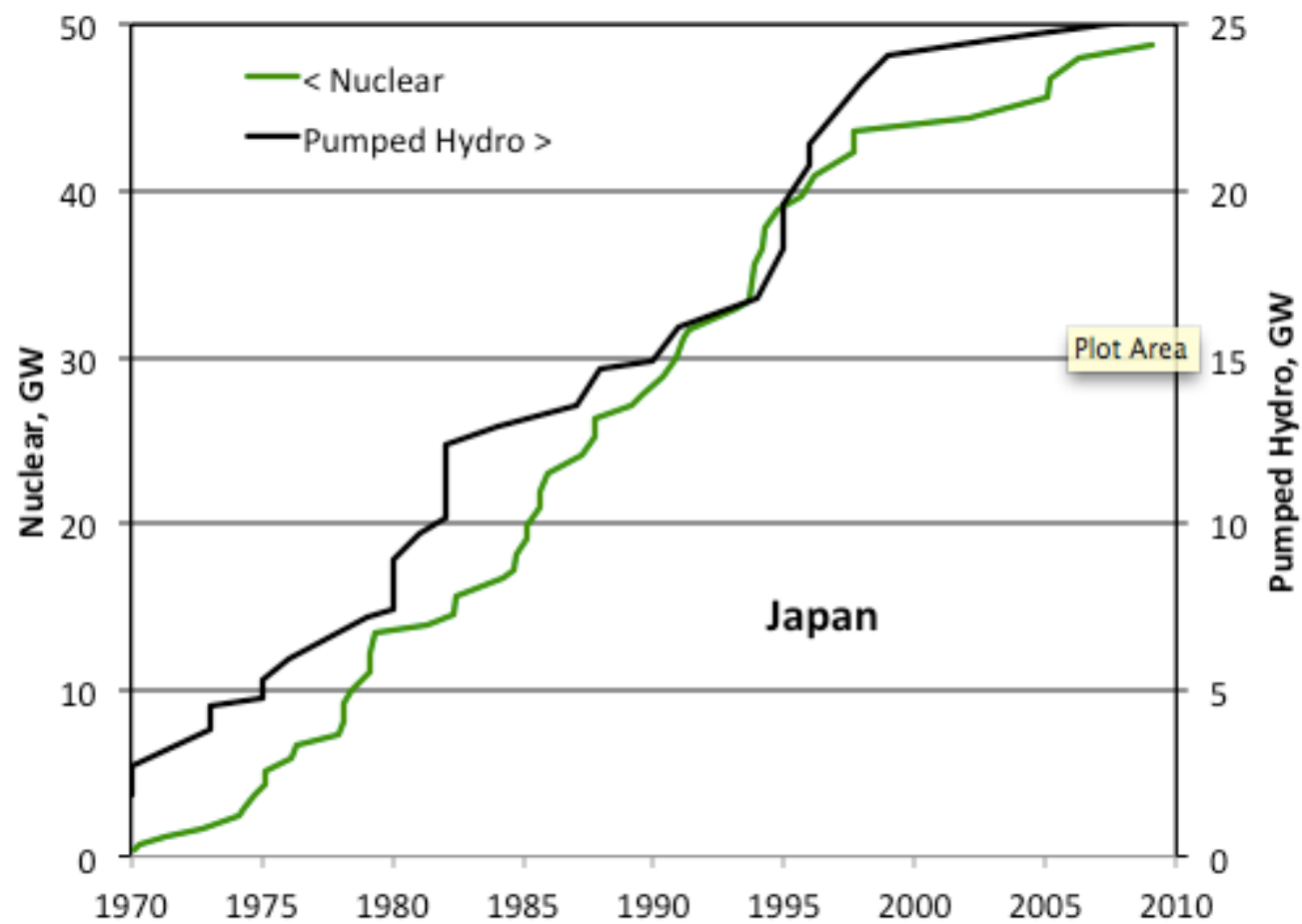
NSW SYDNEY

Storage – Off-peak hot water (NSW residential load 2010)



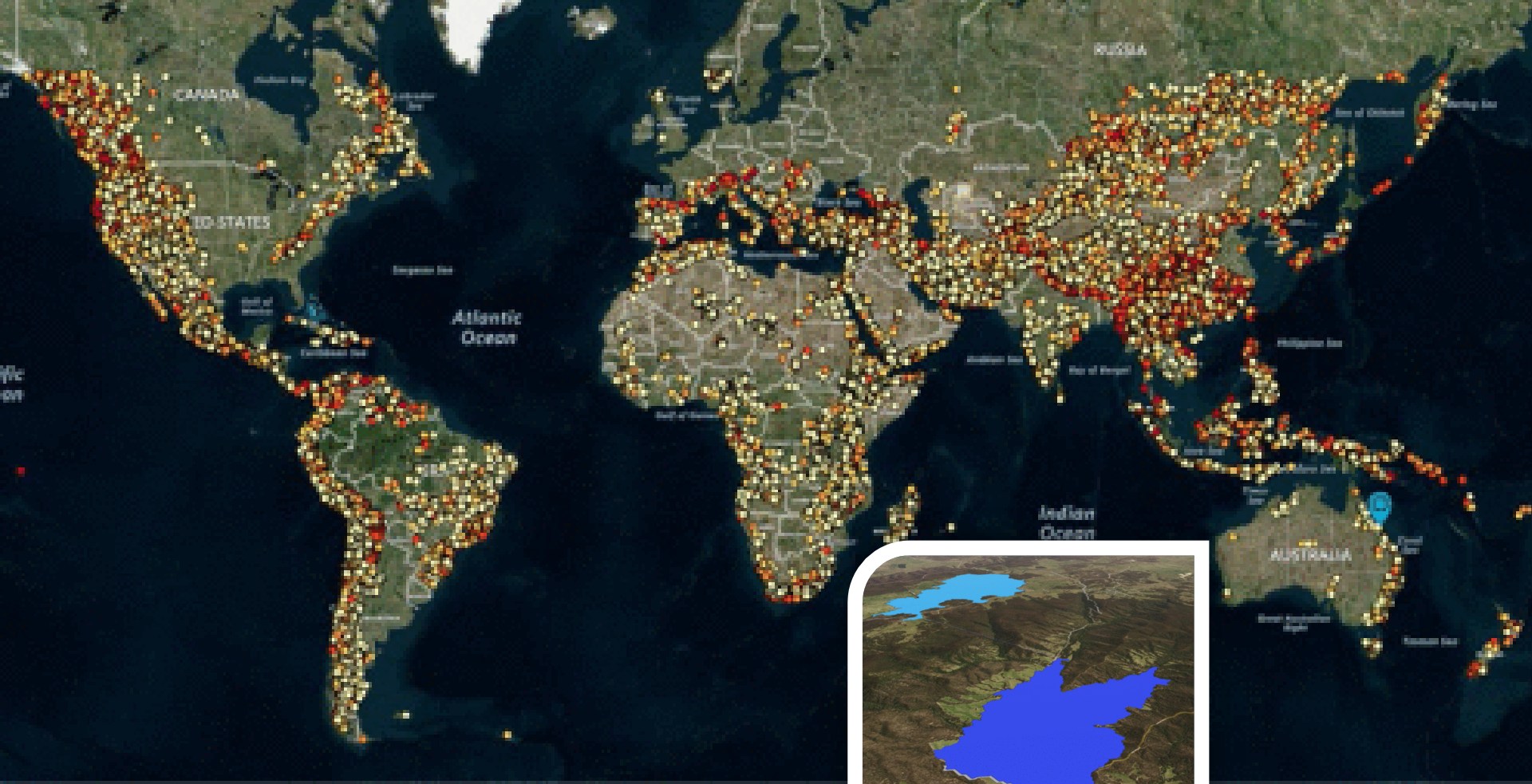
Pumped hydro storage

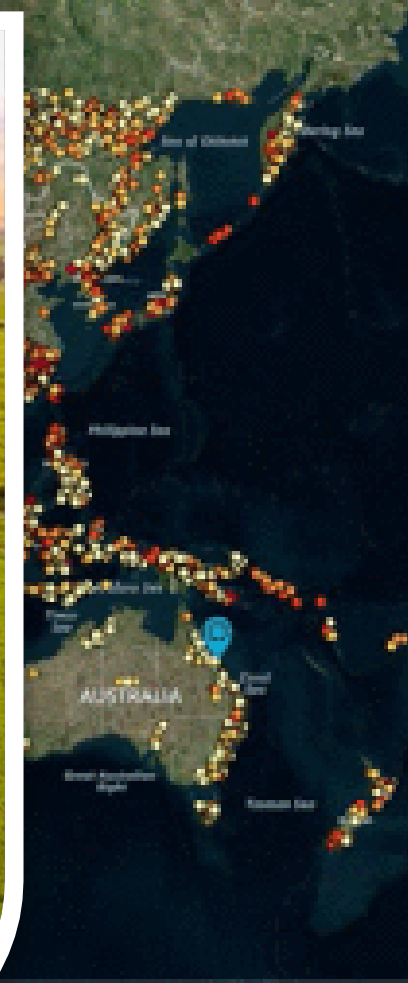




**“Off river” pumped hydro
Presenzano (1GW, 5GWh)**







300MW, 450MWh Li-ion battery



BLUE HYDROGEN

NATURAL GAS



STEAM REFORMING



CO₂ MANAGEMENT



TRANSPORT & STORAGE

ZERO-EMISSIONS
TRANSPORT



INDUSTRIAL
CHEMICALS



POWER GENERATION
& STORAGE



GREEN HYDROGEN

RENEWABLE
ELECTRICITY




ELECTROLYSIS



LIQUEFACTION
& EXPORT



A large industrial steel mill interior. In the foreground, a massive, glowing orange-red steel coil is being processed by a large mechanical arm. Sparks are flying from the point of contact. In the background, two workers in blue protective suits and hard hats stand near a set of stairs with yellow railings. The facility is filled with complex machinery, pipes, and structural steel beams. Steam or smoke is visible in the air.

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

“High Efficiency Silicon Solar Cells”

- . To become “insanely cheap”!
(Ramez Naam)*
- . PERC continues to
accelerate pace of change*
- . 10c/Watt (US\$) modules
within next few years (&
1c/kWh electricity prices)!*
- . Solar to play a major role in
mitigating global warming.*

