“Recent trends in photovoltaics”

Martin Green, UNSW Sydney
Part 1: “Big picture” developments
Module cost history

24x in 12 years!

Average Selling Price (ASP), US$/Watt


US$4.12/W 2008 Q2

US$0.17/W 2020 Q2
Module cost history

Average Selling Price (ASP), US$/Watt

- US$4.12/W 2008

PV Module Weekly Spot Price
- Poly-BSF
- Mono-PERC
- -23%/year
- -21%/year

PV insights
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”
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The graph shows the annual PV installations (GW/a) with a steady increase over the years, reaching 1 TW/a by 2030 with an annual growth rate of 38% per year.

The pie chart illustrates the cell manufacturing capacity share with the following companies: Hanwha (9,600), Zhongrun (10,000), Risen (12,000), Runenergy (12,500), Canadian Solar (19,600), Trina Solar (27,000), JA Solar (30,000), Jinko (31,000), Tongwei (50,000), Aikosolar (40,000), Longi (38,000).

The phrase in the bottom right corner reads: “lowest cost electricity ever seen.”
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. 

Module cost history has shown a significant decrease over the years, with a 24% annual decrease in module costs in 12 years. 

Annual PV installations (GW/a) have shown a dramatic increase, reaching 1 TW/a by 2020. 

CO₂ emissions (Gt CO₂/yr) have peaked in 2019 and have started to decline, with the Rest of World, China, India, EU, and USA making significant contributions to this decline. 

Sample 2°C pathway with a 66% chance for future climate emissions. 

Unresolved problem with significant CO₂ emissions from the USA.
Part 2: PERC takes over the industry
UNSW PERC rules!
Production (MW)

- **Brown bars**: p-mono PERC
- Approx. 95% of c-Si cell production in 2021 will be p-mono PERC:

![Graph showing production (MW) from 2013 to 2021]

Finlay Colville | PV HeterojunctionTech Online
By 2022, more PERC installed than any other cell technology!
Process Optimization of Ingot Pulling Technology

Continuous increase of feeding rate
- Large scale thermal field
- RC2 ingot pulling technology (applied since 2013)

High speed ingot pulling technology
- Pulling speed increased 80%+ since 2013

Mono Wafer Cost Reduction

Production line automation
- Automatic control system
- Automatic edge cleaning system

Mass Production Cost Down
- Wafer slicing cost
- Ingot pulling cost

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.

Diamond wire diameter

Number of wafers from square rods

Slicing speed

2014 to present
PERC offers new functionalities: Cheap bifacial cells!

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)

Source: PVTECH

Honda Dream 1996
PERC: Cheap bifacial cells! Half-cut cells, shingling.
PERC: Cheap bifacial cells! Half-cut cells, shingling

Source: GS-Solar
Size trend of silicon wafer in semiconductor and PV industry
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.

- 1096 mm
- 1754 mm
- 2384 mm
- 1303 mm

In each scenario, Vertex series has 30~90W power advantage over industrial level.

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.

Conventional packing
Horizontal two-tier stack

Innovative packing
Vertical placement

SPACE LOADING CAPACITY PER CONTAINER

+12%

<table>
<thead>
<tr>
<th>Category</th>
<th>Module Power</th>
<th>Pieces per Pallet</th>
<th>Pallet No. per Container</th>
<th>Power per Container</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Module</td>
<td>540W</td>
<td>31</td>
<td>20</td>
<td>334.800W</td>
</tr>
<tr>
<td>Vertex Module</td>
<td>670W</td>
<td>31</td>
<td>18</td>
<td>3739.600W</td>
</tr>
</tbody>
</table>
Part 3: What comes after PERC?
Contending technologies

- PERC, n-PERT
- TOPCon
- HJT
- IBC

Graph showing efficiency improvements over time for different solar cell technologies.
UNSW reported first TOPCon solar cell (1983)

First TOPCon (UNSW)

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
Shift to n-type wafers?

Different cell technology:

- Si-Tandem
- IBC
- HJT
- TOPCon
- PERC
- BSF
- Panasonic HIT (n-type)
- SunPower (n-type)
- Rear HJT (n-type)
- PERC (p-type)
- TOPCon (n-, p-, p-type)
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](chart.png)

- PERC, n-PERT
- TOPCon
- SHJ
- IBC
What comes after PERC? Switch to n-type wafers?

PERC, n-PERT, TOPCon, SHJ, IBC, TCO

Production (MW)

n-type Production by Cell Type

Source: PV Tech, Solar Media Ltd, April 2020
Source: PV Manufacturing & Technology Quarterly report, April 2020 release.
Grass greener on other side?

Background Information

JINERGY (200MW)  
ENN  
ZHONGWEI  
HEVEL  
GS  
RECI  
NEO  
SUNEVIO  
GUODIAN  
SUNPREME  
SANYO  
AIKO  
RISEN (255MW)  
SHANXICOAL (1G)  
AIKO  
AKCOME  
CANADIAN  
M.B.  
TONGWEI (1G)  
HUASHENG

Planned HJT Projects

2010  
2015  
2020  
2021  
2025
Grass greener on other side?
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

![Diagram showing Ingot lifetime (µs) against different resistivity ranges](image)
Grass greener on other side?

2. Problems from mass production line

1) Ingot’s lifetime

![Image of ingot]

**PV Poly Silicon Weekly Spot Price**

<table>
<thead>
<tr>
<th>Item</th>
<th>High</th>
<th>Low</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Grade PolySilicon (9N/9N+)</td>
<td>17.400</td>
<td>10.500</td>
<td>15.630</td>
</tr>
<tr>
<td>2nd Grade PolySilicon (6N-8N)</td>
<td>9.500</td>
<td>8.000</td>
<td>8.470</td>
</tr>
<tr>
<td>N Mono Grade PolySilicon in China (12N/12N+)</td>
<td>17.400</td>
<td>17.050</td>
<td>17.240</td>
</tr>
</tbody>
</table>

Unit: USD/Kg

_Last Update: 2021-03-17_
Grass greener on other side?

2. Problems from mass production line

1) Ingot’s lifetime

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

- PERC $-170\text{um}$

- Tube furnace

- HJT $<130\text{um}$

- In-line equipment
Part 4: What comes after PERC? (long term)
What comes after PERC? – longer term

more sophisticated “active” AR coat?

Supercharged tandem PERC?
What comes after PERC? – longer term

Free choice or Si
What comes after PERC? – longer term

Like silicon, \( ? \) needs to be abundant, non-toxic, stable, efficient (>20%)
What then? – *the end for silicon*?

**Si - 3 cell tandem**

**4-6 cell thin-film tandem**
Part 5: Can solar power the world?
Source of global CO₂ emissions

- Electricity generation: 38%
- Passenger car: 9%
- Freight: 8%
- Cement: 7%
- Chemical: 5%
- Aluminium: 1%
- Other: 8%
- Space heating: 5%
- Water heating: 2%
- Cooking: 2%
- Road other: 3%
- Passenger other: 2%
- Iron & steel: 6%
- District heating & cooling: 3%
Recent studies suggest so!
Recent studies suggest so!
Storage – Off-peak hot water (NSW residential load 2010)

2.8GW
Pumped hydro storage
“Off river” pumped hydro
Presenzano (1GW, 5GWh)
300MW, 450MWh Li-ion battery
“Off river” pumped hydro

'World first' as hydrogen used to power commercial steel production.
‘World first’ as hydrogen used to power commercial steel production
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.