IBC SOLAR CELLS: THE NEXT TECHNOLOGY NODE

David Smith Dec 4, 2024

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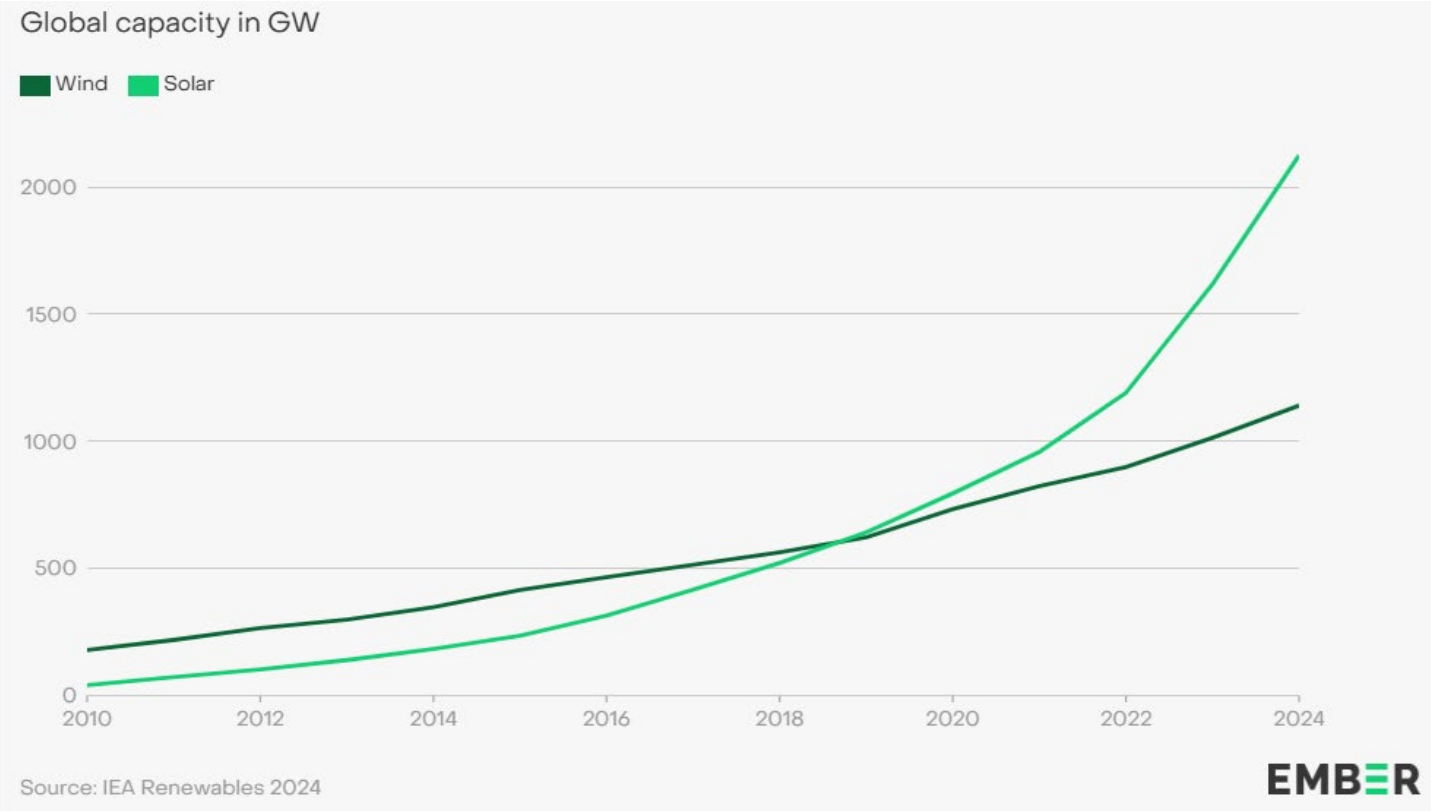
GROWTH OF PV INDUSTRY

- Global use of energy = 170,000 TW-hr
- Current PV share = 7 % of electricity markets
- For 2000 kWhr/kW typical capacity factor, 85 TW is need to power the planet.
- Assume 25 year product replacement cycles
- Sustainable annual PV market in the 2-4 TW range.



- ***There is time for one more PV technology leap prior to steady state market.***
- ***Let's make sure it is a good one…***

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COMPANY AT A GLANCE

Founded in 2020 as a spin-off of SunPower Corporation, Maxeon leverages almost 40 years of experience.

Maxeon is a public company listed on NASDAQ (MAXN).

Headquarters	Singapore
2023 revenues	+1,12 B$
Employees	Approx. 3,900
Experience	Technology leader in the solar industry since 1985
Global reach	100+ Global Markets 1,900+ patents
Customer segments	Residential | Commercial | Power Plants
Channels to market	~1,700 Sales & Installation Partners
Customer-facing brands	SunPower Brand in most of the world Maxeon Brand in U.S. and Japan markets
2023 volume	+2.8 GW shipments
Number of customers	+1,000,000
Manufacturing capacity	+3.5 GW + JV offtake

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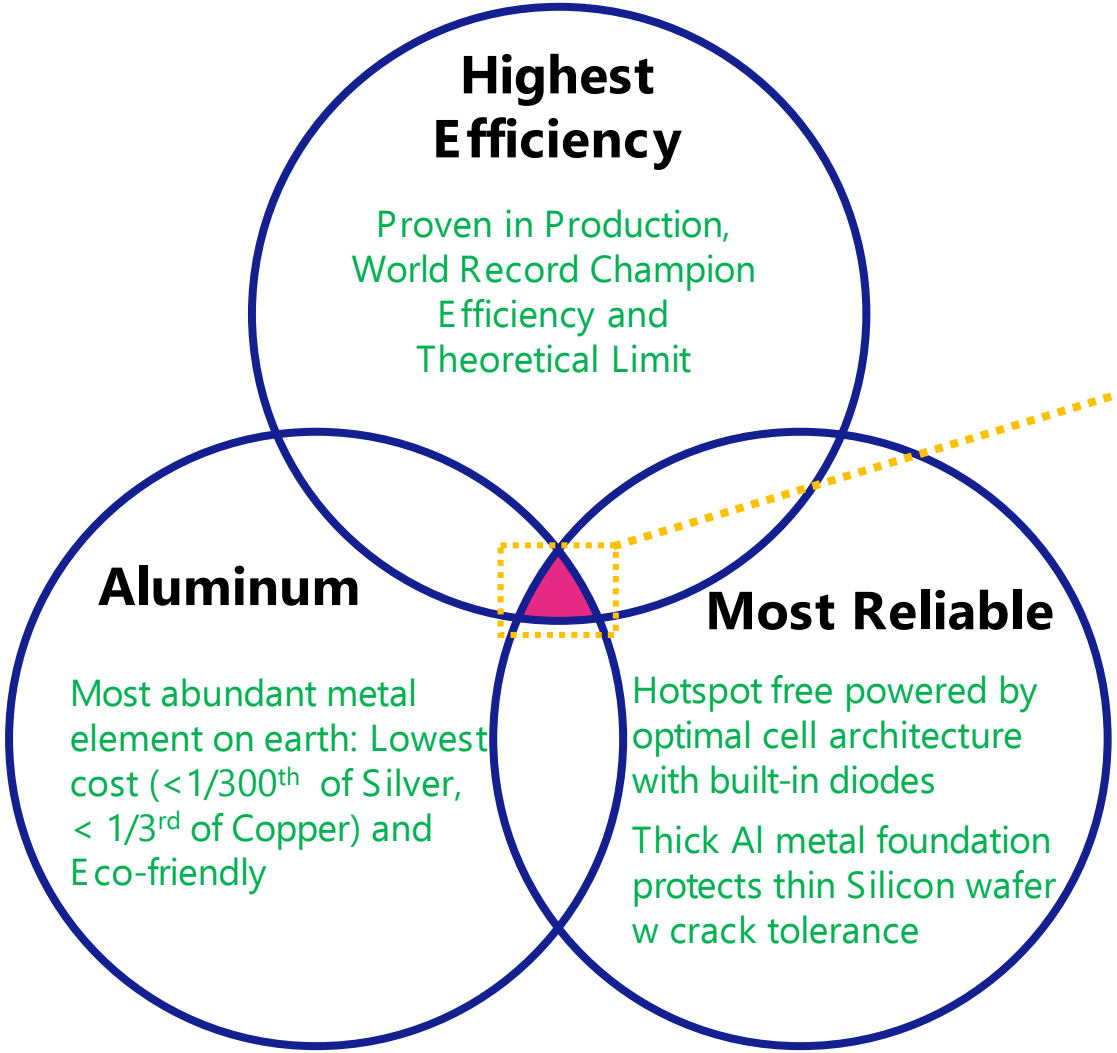
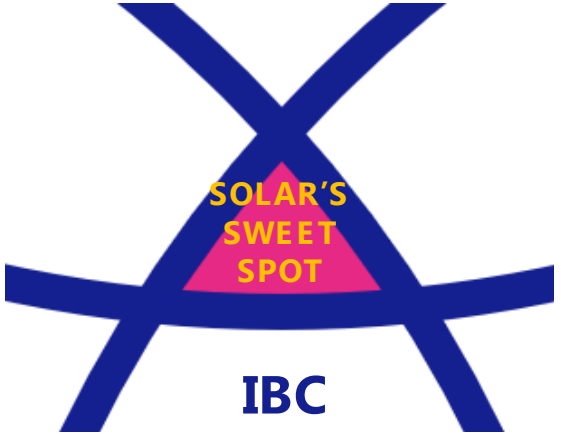
IBC: Ultimate Single-Junction Silicon Solar Cell Technology





With a strong ecosystem, IBC will dominate the solar industry in next 3~5 years!

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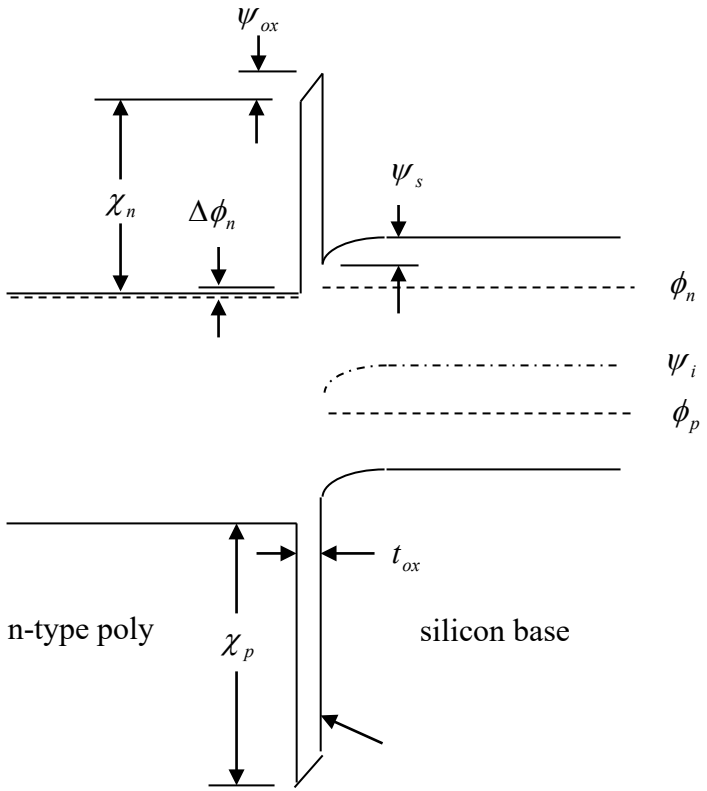
Poly contact



- *Net result: N poly Jo ~ 1 fA/cm2, P poly Jo ~ 6 fA/cm2 contact or non-contact.*

- *Why does it work so well?*

1. *Oxide is buried under poly and annealed never to see moisture or oxygen again.*
2. *Tunnel oxide : Self-limiting growth at polysilicon deposition temperatures.*
3. *Dopant diffusivity thru SiO_2 is just low enough to severely limit out-diffusion.*
4. *Out-diffusion is not zero as in Hetero-junction a-Si emitter. Insensitivity to surface prep and defects. For example, particles under-diffused.*
5. *Metal gettering to Npoly.*
6. *Damage in poly is irrelevant, buffers post-process issues.*

Redundancy. Multiple levels of protection.

Poly emitter band structure for N-type
- ✓ *Pile-up of majority carriers at surface*
- ✓ *Reduction of minority carriers without Auger penalty*

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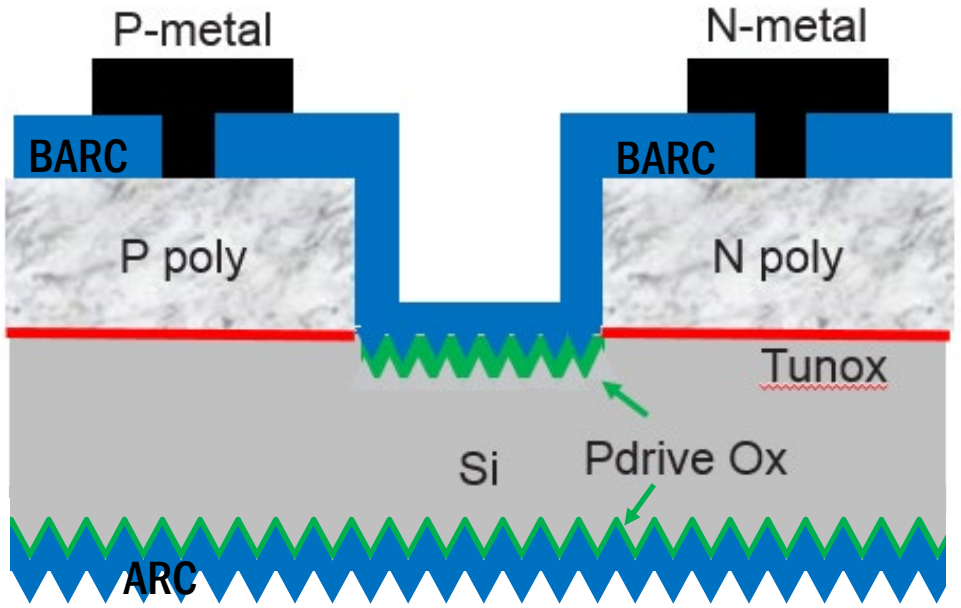
IBC IMPLEMENTATION

- IBC use of polysilicon limited by space charge recombination at butting junction.
- Multiple solutions, but most robust is trench process.
- Utilized on Maxeon 3/5/6 products to demonstrate PV industry's first 22 % efficiency modules.
- *Roadmap: Self-aligned process.*



Maxeon 3 device structure. First demonstrated April 2008.

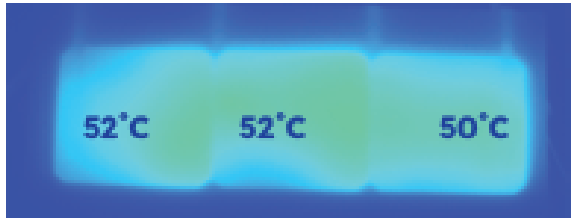
Patents: EP 3065184
US 7812250
CN 102057497

REVERSE BIAS AND SHADING

Conventional cell

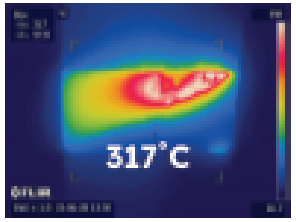
Thermal image of a conventional cell with a defect and failed bypass diode

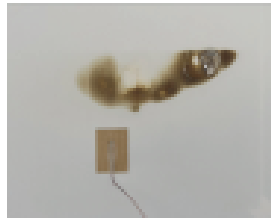
Maxeon's latest-generation IBC



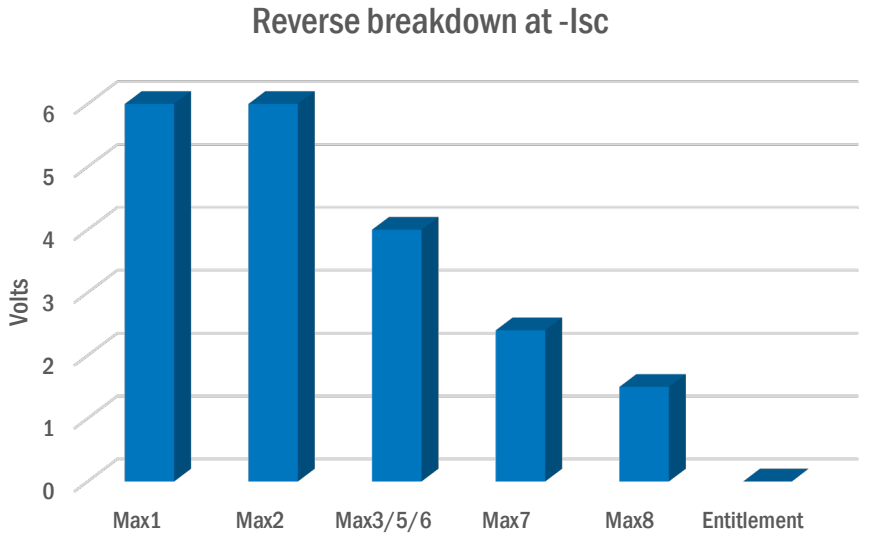
Maximum temperature of Maxeon IBC cells at -Isc in reverse bias with no diodes, 20°C ambient

A competitor's IBC





A competitor IBC module with partial shading of a cell and diodes removed resulted in backsheet burning within 30 minutes



- Max7 reverse voltage at –Isc is -2.3 volts.
- Shaded conditions increase cell temperature only 30 C
- Higher energy yield and fewer reliability issues with local heating.
- Compare to conventional front contact with very elevated temperatures during diode failure.

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What Happened?

- ❑ Generally steady progress thru 2008.
- ❑ Sunpower was efficiency, reliability and cost leader thru this period. Then…

Sunpower	Rest of industry	Consequence
$40/kg Polysilicon contracts		~ 1 $B loss
5 inch wafers	M2-M4-M6-G10-G12	High silicon cost, captive supply chain
Specialized inline tools	Large batch	Capex disadvantage, limited growth
High overhead small factories	Local supply chains, China national priority	Persistent high-cost structure
23 % cell in 2008, market introduction 2016	AlBSF → PERC → Topcon	Erosion of efficiency advantage, Time to market delay

Innovation History of Maxeon IBC Solar Cells

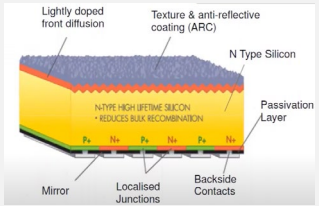
Era of Diffused Contact

Cell Eff. Limit in Prod. w NREL calibration

Max1/2: 23% cell eff.
Voc 690 mV, Vbr -5 V

Birth of IBC
Stanford Professor Richard Swanson invented IBC and founded SunPower

1985



1990

US5030295 : SiO_x & Poly-Si stacks

US5057439 : Poly-Si emitters for solar cells

2005

US7468485: Back side contact solar cell with doped polysilicon regions, exp. date: 2/28/2027

Era of Poly-Si Contact

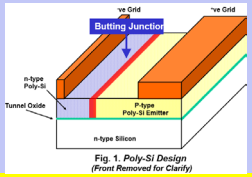
Max3: 24.5% cell eff.
Voc 730 mV, Vbr -3.5 V

Max7: 25.5% cell eff.
Voc 743 mV, Vbr -2.3 V

Max8: 26.5% cell eff.
Voc 750 mV, Vbr -1.5 V

2008

EP3065184B1/US7812250 /CN102057497: Poly Si regions separated by trench structures, exp. date: 4/29/2029



Solve space charge recombination

2012

EP2936570B1/ US9312406B2: Poly Si + Diffusion, exp. date: 12/15/2033

2013

US8962373B2: Poly + Heterojunction, exp. date: 12/21/2031

2020

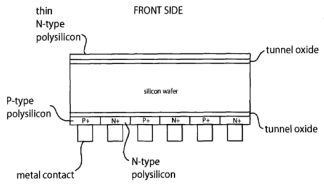
US10840392B2/ EP3123525B1: Two different tunnel oxide materials, exp. date: 3/28/2034

US9196758/US9634177/EP3084840: Two poly layers with sidewall oxide isolation, exp. date: 12/15/2034

2023

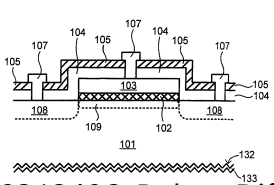
US12074234B: Discrete islands of poly surrounded by self-aligned trench, exp. date: 3/19/2043

Key Patents for Max8 and beyond technical routes!

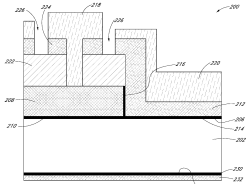


US7468485

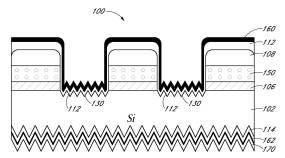
There were many years of Poly-Si contact development, but fundamental issue was not resolved to enable a high eff. Poly-Si IBC cell



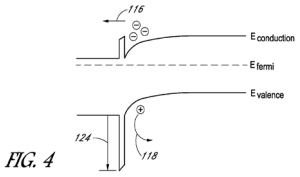
US9312406: Poly + Diff



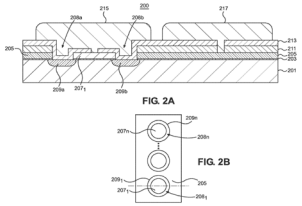
US9196758



US8962373: Poly + HJT



US10840392



US12074234B: Poly Islands

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1. Achieved 11 World Records in NREL Champion Cell and Module Efficiency Chart
2. IBC is the technology beyond TOPCon and is an excellent platform for Tandem

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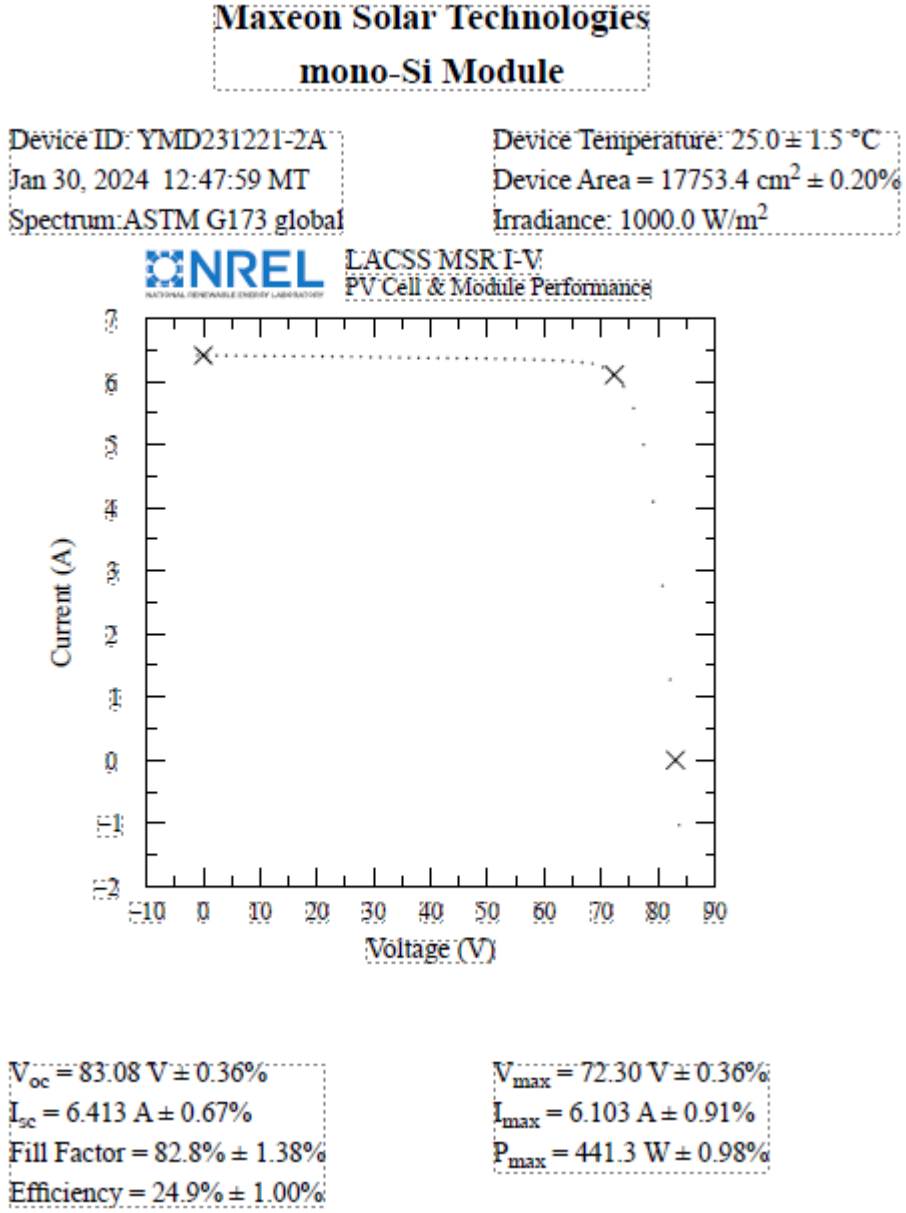
- Max7 product was making 24 % efficiency white backsheet modules in 2023.
- Champion aperture tested module of 24.9 % in January. 83.08 V/112 cells = 742 mV Voc per cell.
- Max7 stuck in pilot operation due to factors beyond our control
    1. Inventory overhang due to industry over-capacity
    2. Detention of Maxeon products at US border by CBP
- Max8 product anticipated to be 25 % efficiency total area, 750 mV per cell.



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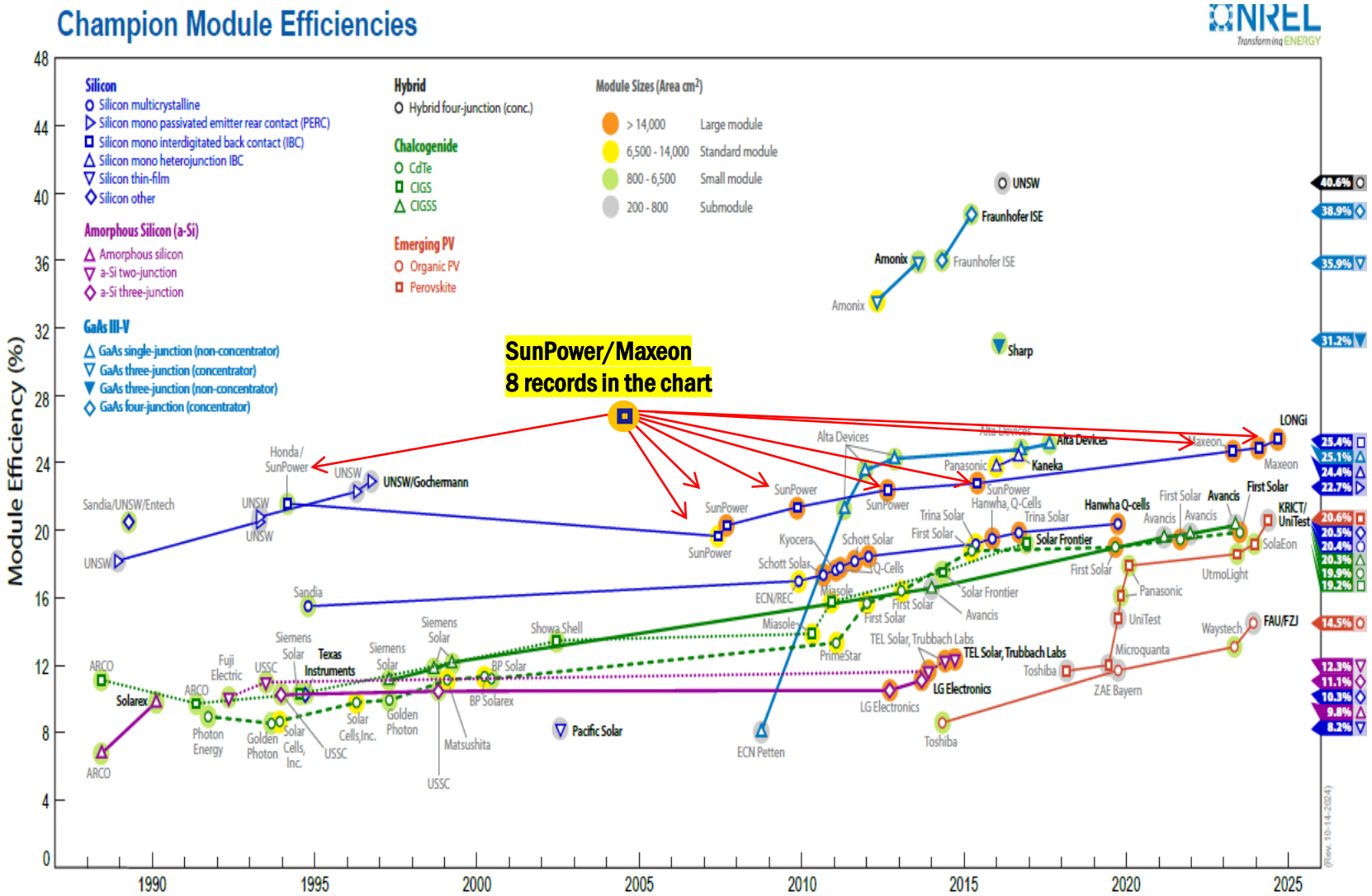
BACK CONTACT INNOVATION LEADERSHIP

Maxeon IBC: Industry-leading efficiency and reliability. Developed in Silicon Valley, California, USA.

- R&D center in San Jose, CA
- **100+** R&D personnel
- **>1900** patents, most on structures and manufacturing processes for IBC solar cells and modules
- **>20** years experience with high volume IBC manufacturing



https://www.nrel.gov/pv/assets/pdfs/champion-module-efficiencies.pdf

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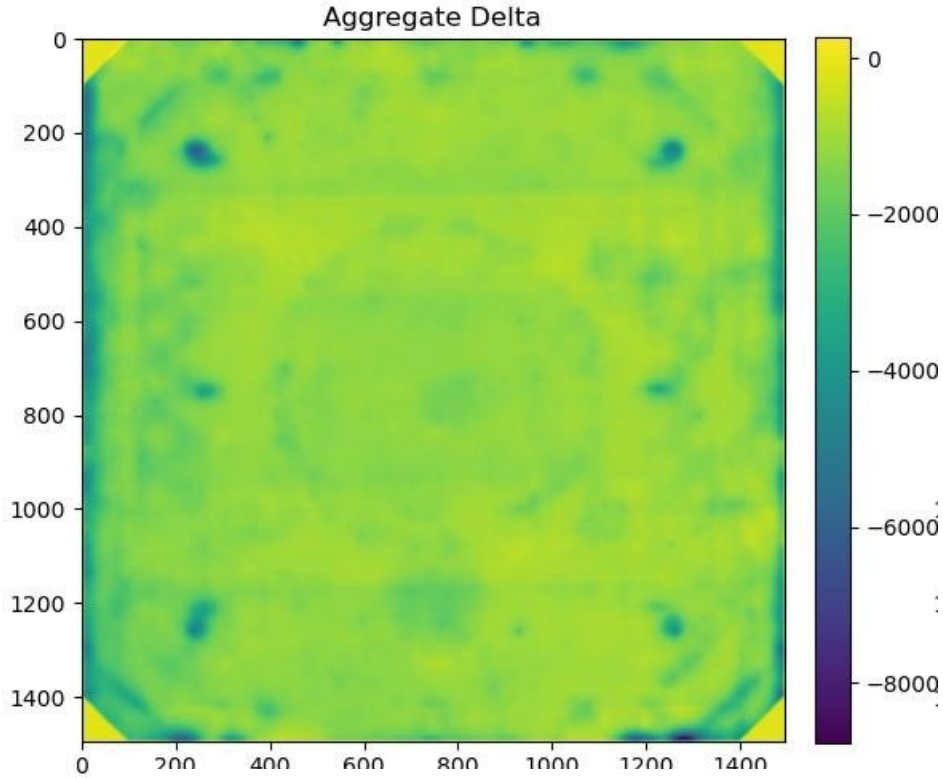
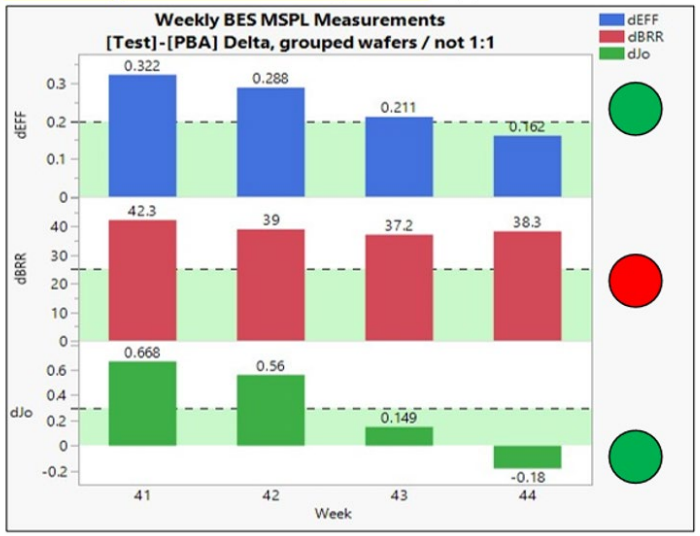
YIELD

- Maxeon is largely past the era of metal contaminants limiting bulk lifetime.
- Majority of defects are handling related.
- Key method: Aggregate PL data to detect recurring defects
- Frequently found in metallization processes
- Each process step monitored. Total backend handling losses near 0.2 % efficiency.
- Many small defects that need continuous focus.



BE Segmentation (Weekly)



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MAXEON 8 IBC

- 25%+ module efficiency
- Low reverse bias
  - Excellent energy yield, passive safety.
- Aluminum Metallization
  - Crack tolerance
  - Lead-free
  - Hail resistant (critical for UPP market)
- 40+ year warranty, lower annual degradation
- Differentiated product in both DG and UPP markets.
- Extensive IBC IP portfolio
- Equivalent manufacturing complexity and structural cost to TopCon.

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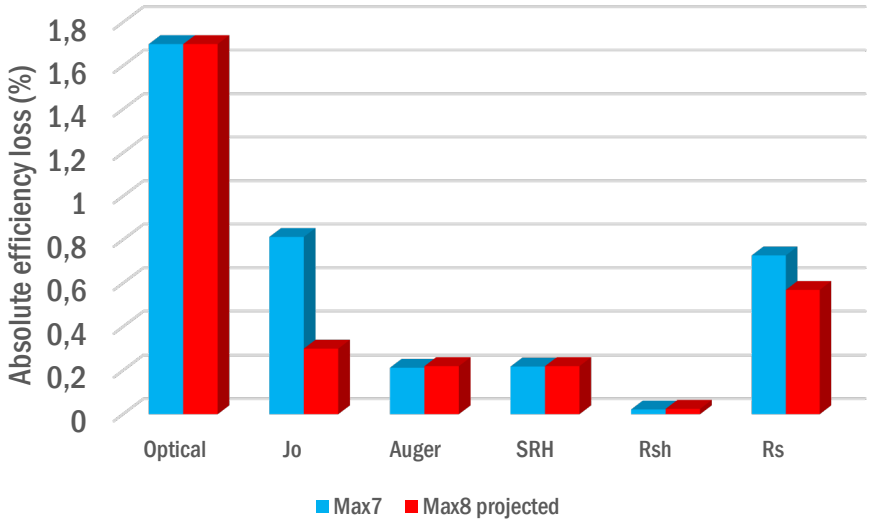
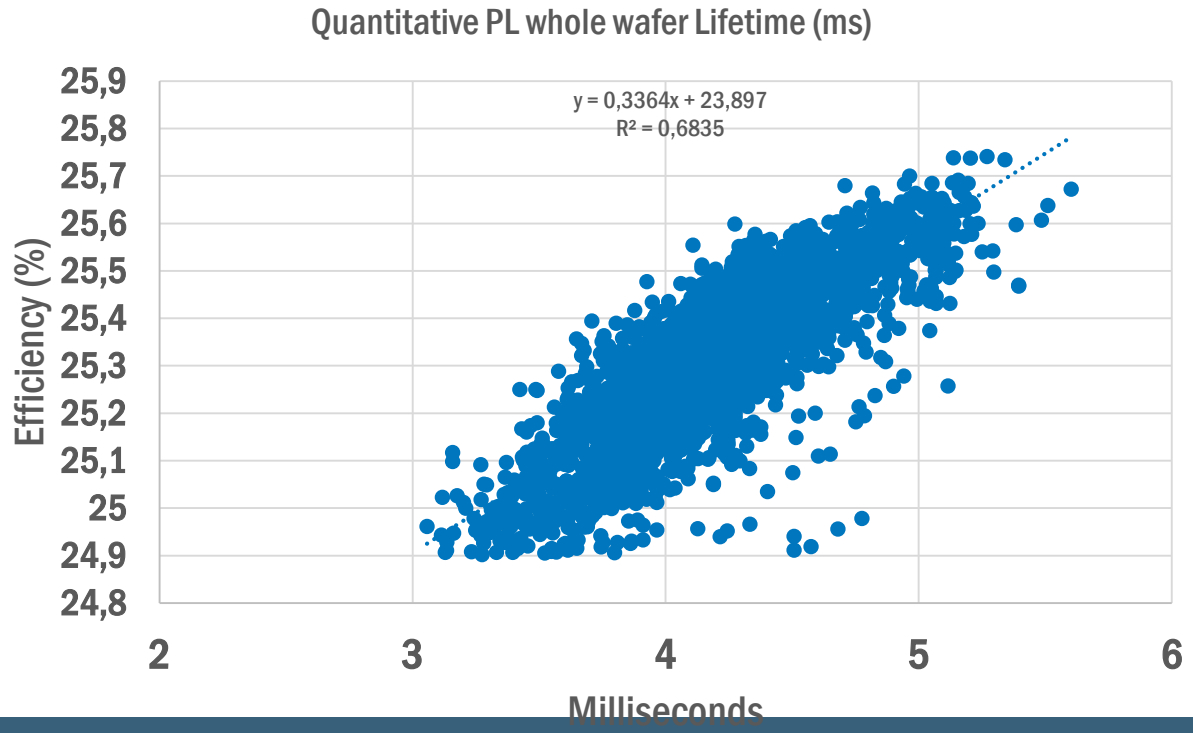
MAXEON 8

- Currently prototyping on Maxeon 7 process with no step additions. Self aligned micro-trench structure.
- Efficiency loss analysis for Maxeon 7 and projected for Maxeon 8 at right.
- Bulk lifetime 20 msec typical no longer significant loss, Jo losses will become small with Max8
- Anticipate > 26 %
- Largest remaining loss: poor infrared absorption





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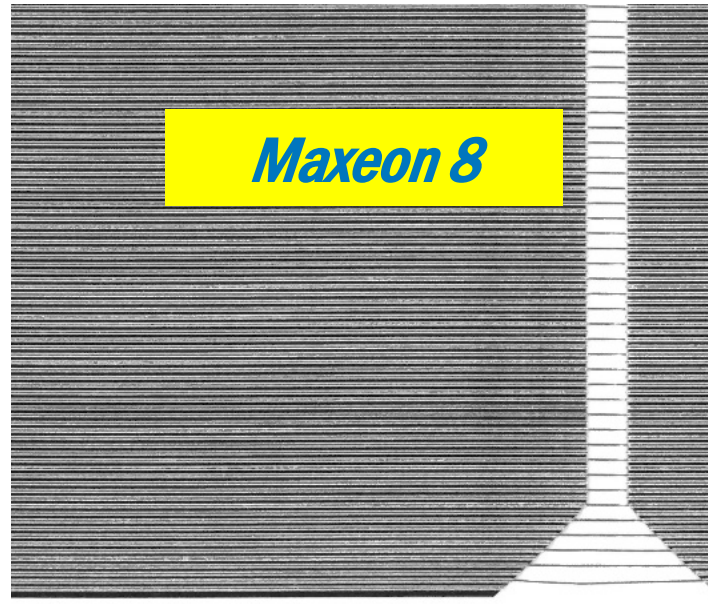
Aluminum wires metallization

- Maxeon 8 – Aluminum wire metallization system for cells, stringing, and matrix formation
- 25.3 % demonstrated, higher potential than copper, no solder pad dead space.
- Exceptional crack tolerance with high-strength wire continuously bonded to the cell
- Exceeds reliability tests for 40-year warranty
- Metal costs 30% of standard TOPCon systems, Aluminum $3/kg, Silver $1000/kg
- Developed in San Jose R&D lab, ongoing pilot line startup in Philippines

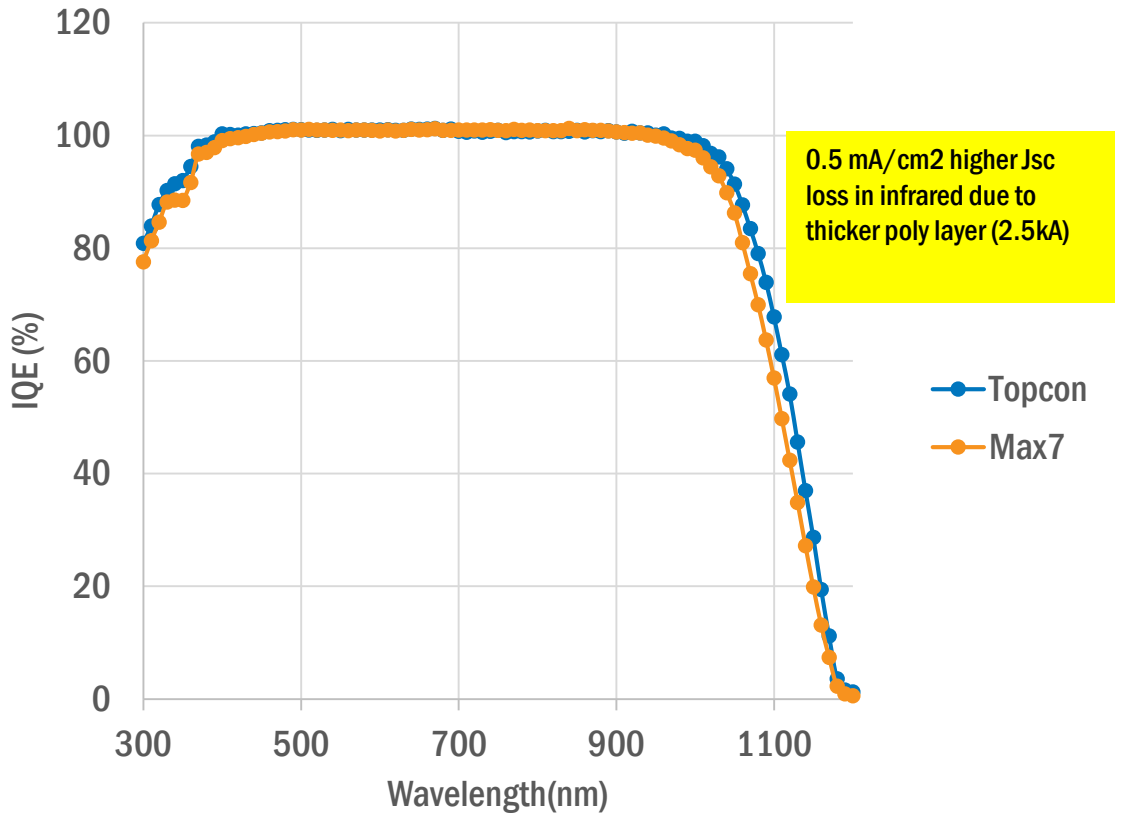


MY VISION OF MAXEON IBC ROADMAP

1. Zero volts reverse breakdown for best reliability and energy yield.

2. Improved free carrier absorption
   - ❑ Poly thickness currently well above Topcon at 2.5kA. Total available loss estimated at 0.5 %. Likely half accessible.

3. Advanced light trapping scheme.
   - ❑ *Only thing that can enable >27 % cell and 26 % efficiency module.*



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Thank you!

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POWERING POSITIVE CHANGE