

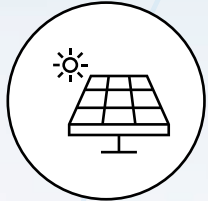
Next-Gen PV: TOPCon Ultra and Perovskite/Silicon Tandem Technology

Ethan Ely

Product Manager
Trinasolar U.S.

- Trina R&D Background
- TOPCon Ultra Technology
- Tandem Technology Introduction
- Perovskite + Silicon Advantage
- Tandem Development Progress
- Key Challenges of Perovskite / Silicon Tandem Cells
- Intellectual Property of Perovskite Solar Cells
- Summary

Trinasolar: R&D Leadership

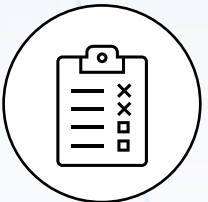


Founded in 1997, serving 180 countries with **25+ years** of technology leadership



#1 globally with **200GW+** of 210mm module shipments

As of June 2025



World's first **TÜV Rheinland IEC certified witness test laboratory** and **CNAS Accredited test laboratory**

From 2010-2025, achieved **35 world records** for PV cell efficiency and module output

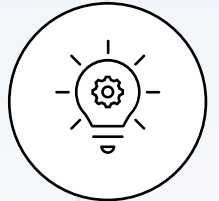
As of June 2025



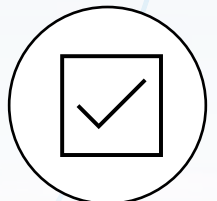
PVEL Top Performer for **11 consecutive years** and RETC Overall Highest Achiever **5 times**



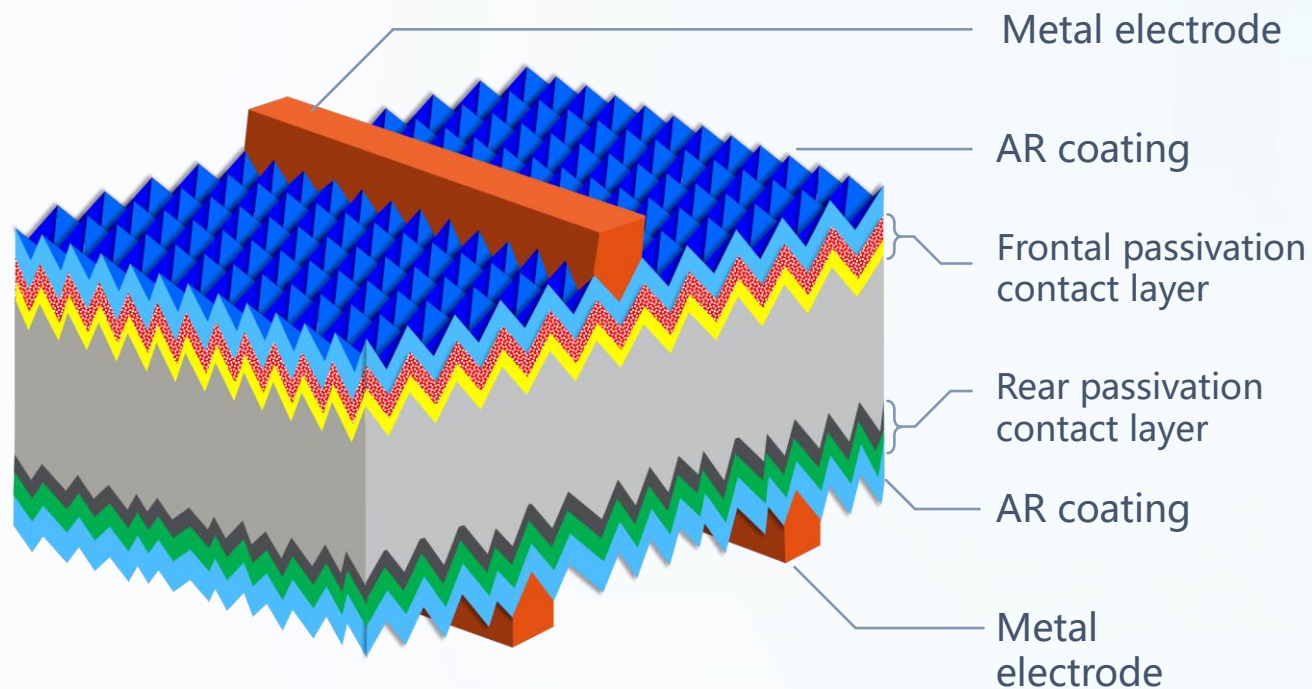
Granted **3400+ patents** including **500+ TOPCon patents**



Participated in formulation of **230 industry standards** and received certification **170 standards**



Next-Generation Cell Tech: TOPCon Ultra



Double-Side Full Passivation

Both front and rear metal contact areas use passivated contact technology

Optical Parasitic Absorption Suppression

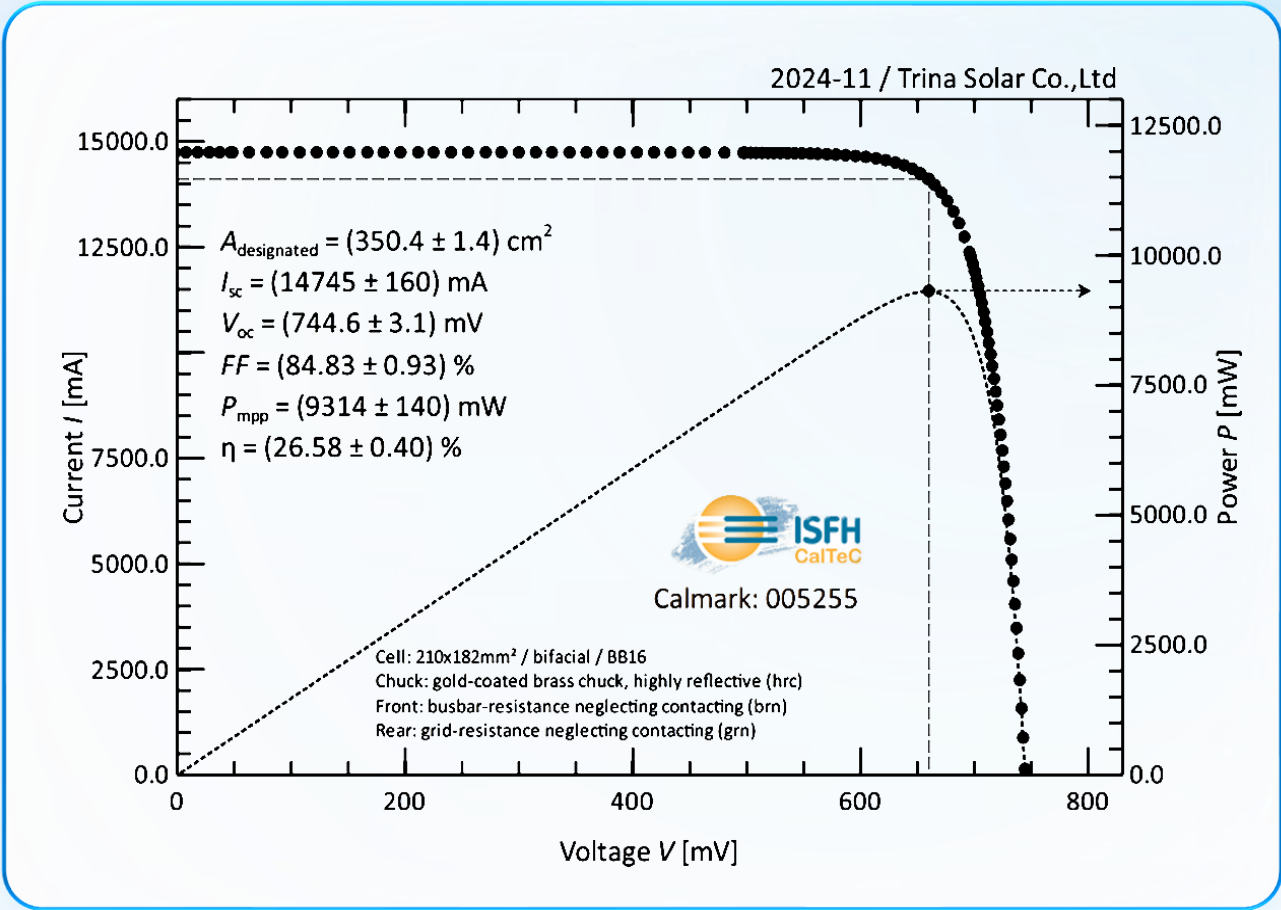
Using specialized structures and processes to reduce parasitic absorption in the passivated contact layer

Ultra-Thin Busbar Technology

Narrowing busbar thickness to $<15\ \mu\text{m}$

Cell efficiency increases of over 1.0%, module power increases of 30W+

New TOPCon Record: 26.58% Cell Efficiency



TOPCon Ultra Cell Efficiency of 26.58%
certified by Solar Energy Research in Hamelin
(ISFH) in Nov. 2024

The 28th time Trina Solar has broken the cell
efficiency world record

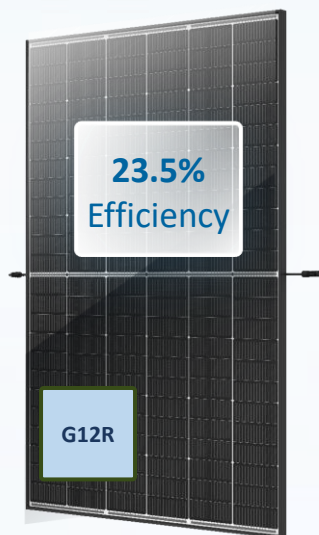
The first time that N TOPCon cell efficiency
surpasses 26%

Achieved on flagship 210R wafer

	V_{oc} [mV]	J_{sc} [mA/cm ²]	FF [%]	η [%]
Front	744.6	42.1	84.83	26.58

Next-Generation TOPCon Ultra Module Portfolio

Vertex S⁺
TOPCon Ultra



Up to
470W

Small format module
Residential Rooftop

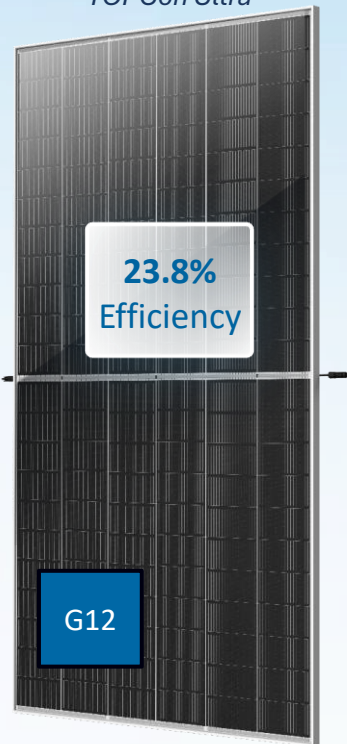
Vertex N
TOPCon Ultra



Up to
650W

Medium format module
C&I Rooftop, Ground-Mount, and Utility

Vertex N
TOPCon Ultra



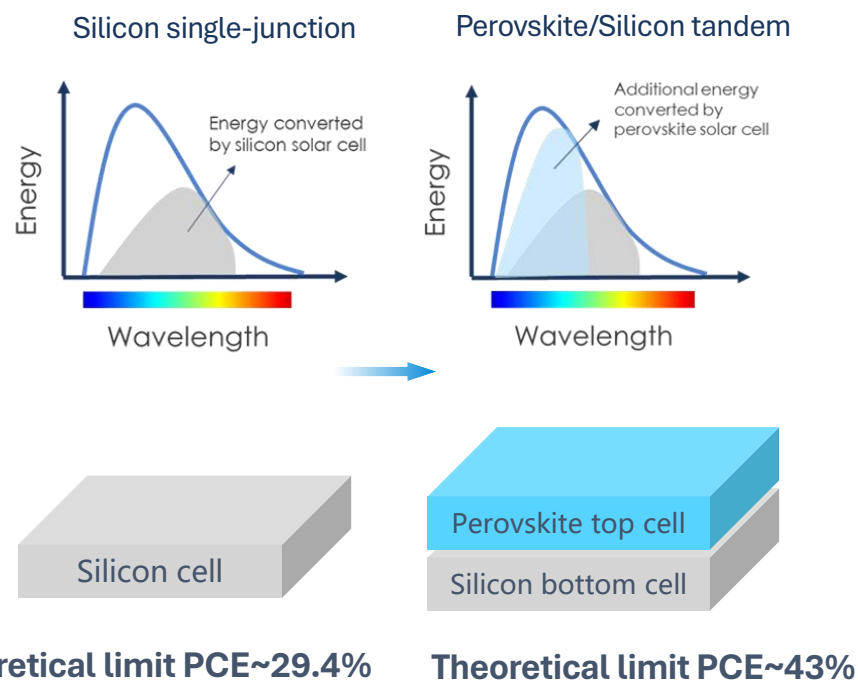
Up to
740W

Large format module
Large-Scale Utility

Pushing the Limits: Tandem Technology

Single-junction cells are approaching practical efficiency limits of 29.4%.

Tandem solar cell technology enables potential cell efficiency of **up to 43%** by expanding conversion potential of solar wavelengths.

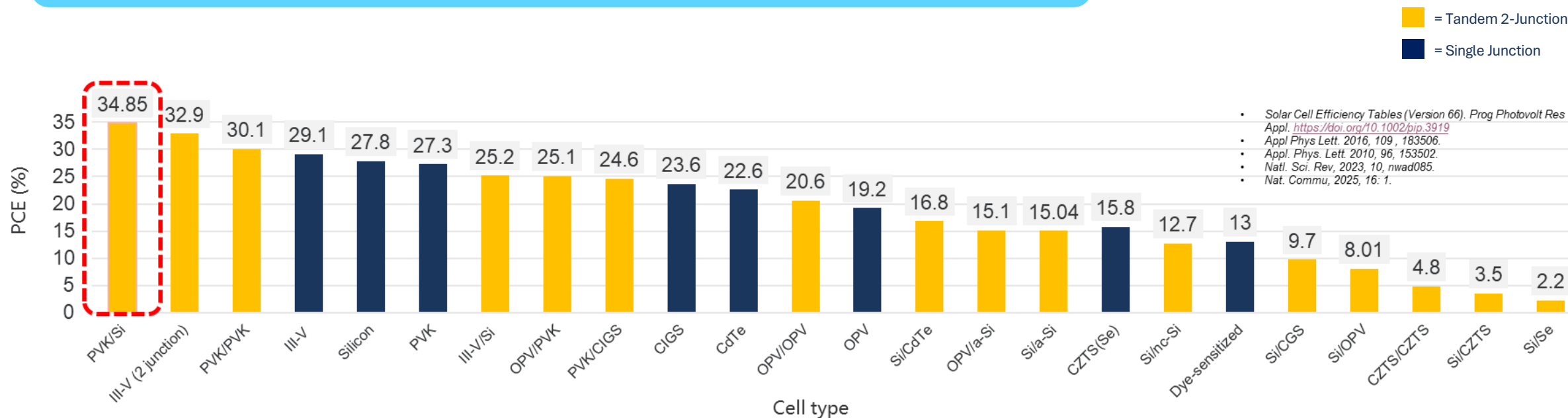


Source: Andres M. Bett(2022), The Promise Towards Terawatt Photovoltaics
Green et al. PIP 2025 (0) P1-16
Oxford PV(2021)

Cell	Lab champion	Industrial average	Eff. gain
AI-BSF	~21%	~20%	
PERC	25%	~24%	+4%
TOPCon	26.6%	~26%	+2%
HJT	27.1%	~26.2%	<1%
TBC	27%	~26.5%	
HBC	27.8%	26.8%	+5%
Tandem	~35%	>31%	

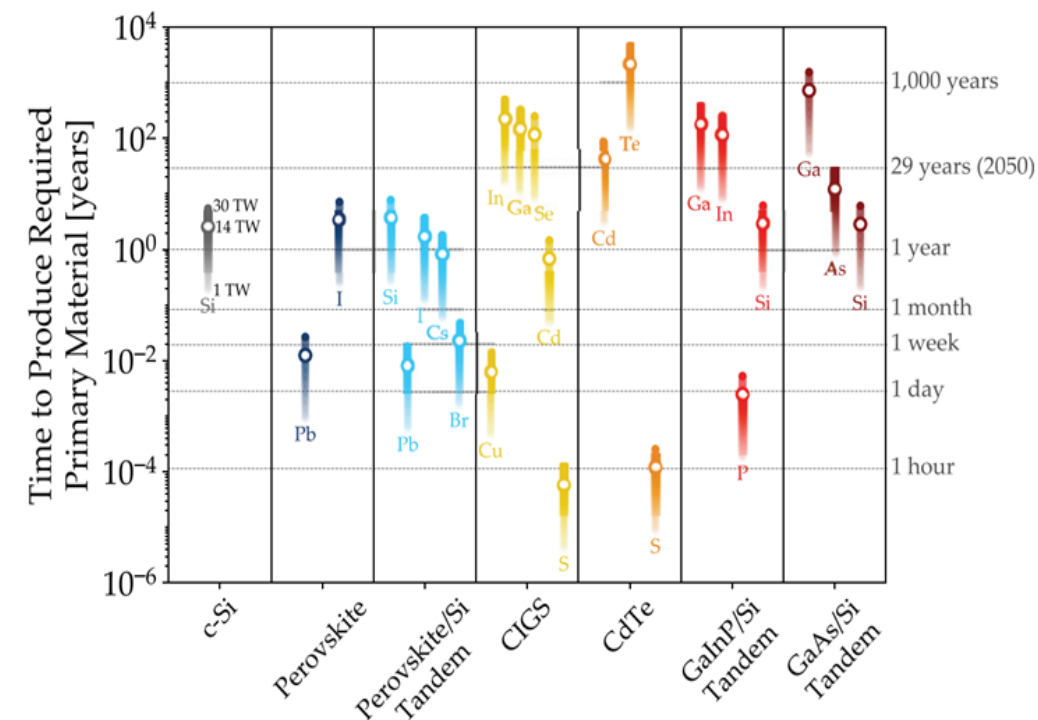
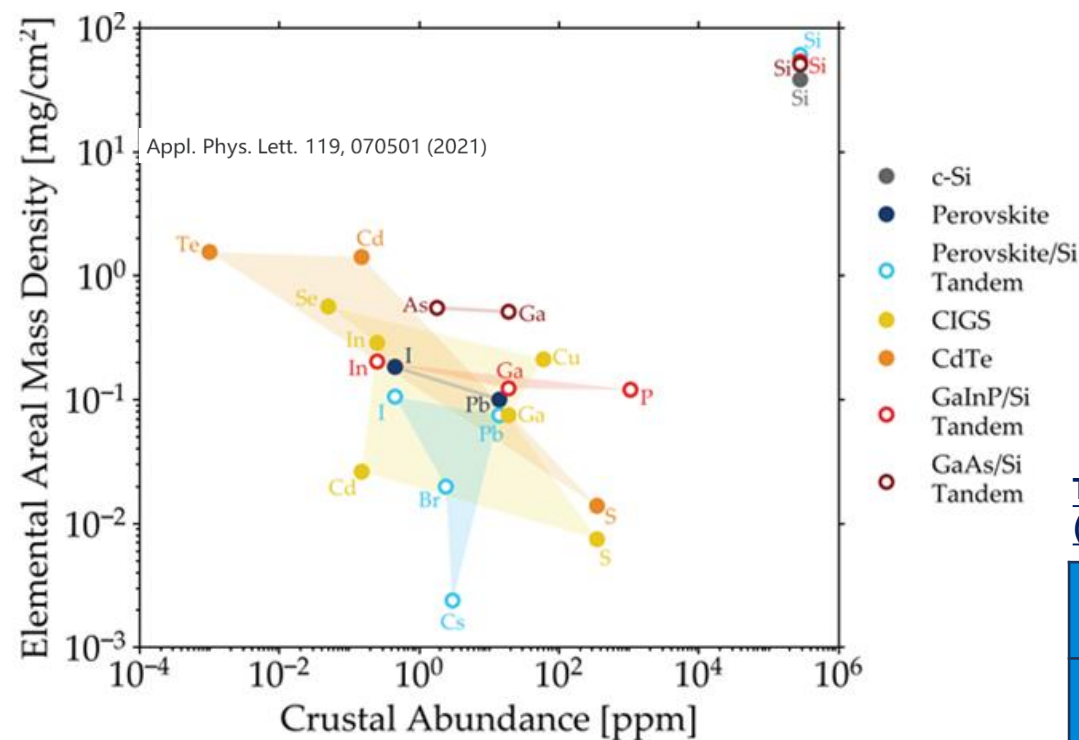
Perovskite + Silicon: Superior Combination

Perovskite/Silicon 2-Terminal tandem cells can achieve the highest Power Conversion Efficiency (PCE) among other 2-Junction Tandem PV technologies.



Perovskite + Silicon: Abundant and Cost-Effective

Perovskite/Silicon 2-Terminal tandem cell materials are considerably more abundant than competing technologies and offer shorter production time horizons.

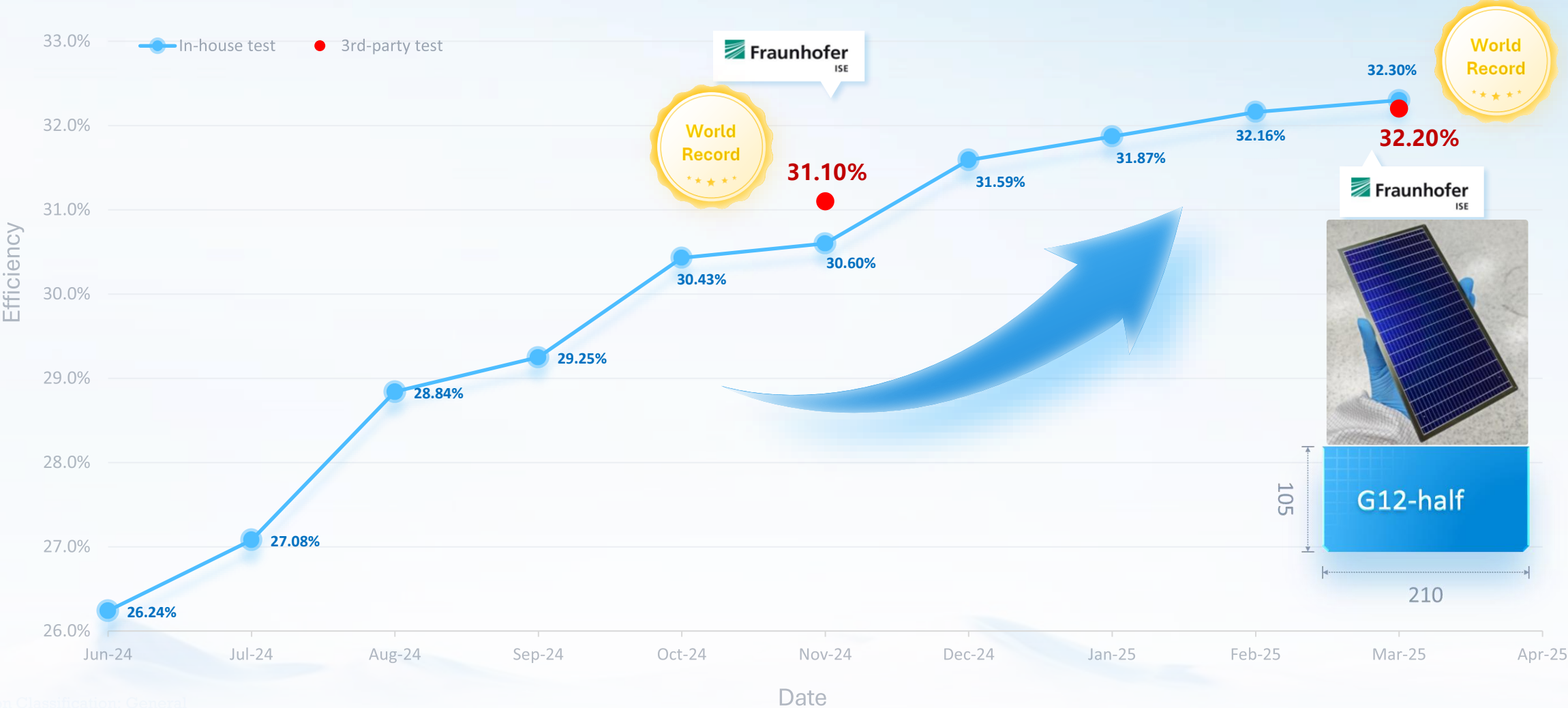


Time to Produce 1TW of Primary PV Absorber Material
(assuming 100% market share of a single technology)

PV Technology	Silicon	Perovskite	Perovskite /Si Tandem	Cadmium Telluride	CIGS	GaAs/Si Tandem	GaInP/Si Tandem
Controlling Element	Si	I	Si	Te	In	Ga	Ga
Required Time	1 year	1 year	1 year	100 years	20 years	80 years	20 years

Trina's Tandem Cell Performance: Record-Setting Efficiencies

From Jun. 2024 to Mar. 2025, the efficiency of the 210 half-cell was increased from 26.24% to more than 32%



Tandem Module Performance: Breaking the 30% Barrier

April 2025 – Trina Solar sets new world record for perovskite/silicon tandem solar module efficiency of **30.6%**

The world’s first tandem module with efficiency **>30%**

Independently certified by Fraunhofer ISE, included in 《Solar Cell Efficiency Tables》 (Version 66)

Perovskite/Si	30.6±1.3 ^e	1185.6 (da)	11.783	3.578 ^a	86.1	FhG-ISE (4/25)	Trina [52]
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1185.6 cm² (2x3 cells)

TABLE 5 Confirmed non-concentrating terrestrial module efficiencies measured under the global AM1.5 spectrum (1000 W/m ²) at a cell temperature of 25 °C (IEC 60904-3:2008 or ASTM G-173-03 global).							
Classification	Effic. (%)	Area (cm ²)	V _{oc} (V)	I _{sc} (A)	FF (%)	Test Centre (date)	Description
Si (crystalline)	26.0±0.3	18,156 (da)	40.38	13.896 ^a	84.0	NREL (12/24)	LONGI, HBC [4]
Si (crystalline)	25.4±0.4	16,279 (ap)	56.09	8.58 ^a	86.0	FhG-ISE (12/24)	Trina, HJT [64]
GaAs (thin-film)	25.1±0.8	866.45 (ap)	11.08	2.303 ^b	85.3	FhG-ISE (11/17)	Alta Devices [65]
CIGS (Cd-free)	19.2±0.5	841 (ap)	48.0	0.456 ^c	73.7	AIST (1/17)	Solar Frontier (70 cells) [66]
CdTe (thin-film)	19.9±0.3	23,932 (da)	231.5	2.675 ^d	77.1	NREL (6/23)	First Solar [67]
Perovskite	19.2±0.4 ^e	1027 (da)	59.4	0.4307 ^a	77.1	NREL (12/23)	SolaEon [68]
Organic	13.1±0.3 ^f	1475 (da)	48.10	0.6015 ^g	67.0	NREL (5/23)	Waystech/Nanobit [69]
Multijunction							
InGaP/GaAs/InGaAs	32.65±0.7	965 (da)	24.30	1.520 ^b	85.3	AIST (2/22)	Sharp (40 cells; 8 series) [70]
Perovskite/Si	30.6±1.3 ^e	1185.6 (da)	11.783	3.578 ^a	86.1	FhG-ISE (4/25)	Trina [52]
Perovskite/Si (large)	26.9±1.0 ^e	16,023 (da)	56.18	9.456 ^d	81.1	FhG-ISE (6/24)	Oxford PV [71]
a-Si/n ⁺ -Si (tandem)	12.3±0.3 ⁱ	14,322 (t)	280.1	0.902 ^j	69.9	ESTI (9/14)	TEL Solar, Trubbach Labs [72]
‘Notable Exceptions’							
CIGS (large)	18.6±0.6	10,858 (ap)	58.00	4.545 ^k	76.8	FhG-ISE (10/19)	Miasole [73]
InGaP/GaAs/Si	33.7±0.7	775 (da)	20.3/2.83	1.25/1.93 ^l	86.5/78.0	AIST (2/23)	Sharp/Toyota TI, 4-term [74].
InGaP/GaAs/CIGS	31.2±0.7	778 (ap)	20.3/16.9	1.24/26 ^m	85.7/59.8	AIST (2/23)	Sharp/Idemitsu, 4-term [74].
Perovskite (large)	18.1±0.6 ^e	7218 (t)	93.56	1.876 ⁿ	74.4	NREL (1/25)	UtmoLight [75]



Full-Size Tandem Module Prototype

The world's **first industrially-sized** perovskite/ silicon tandem module was officially unveiled with certified power of **808W** on Nov. 2024. It was upgraded to **829W** in May 2025 and **841W** in June 2025.



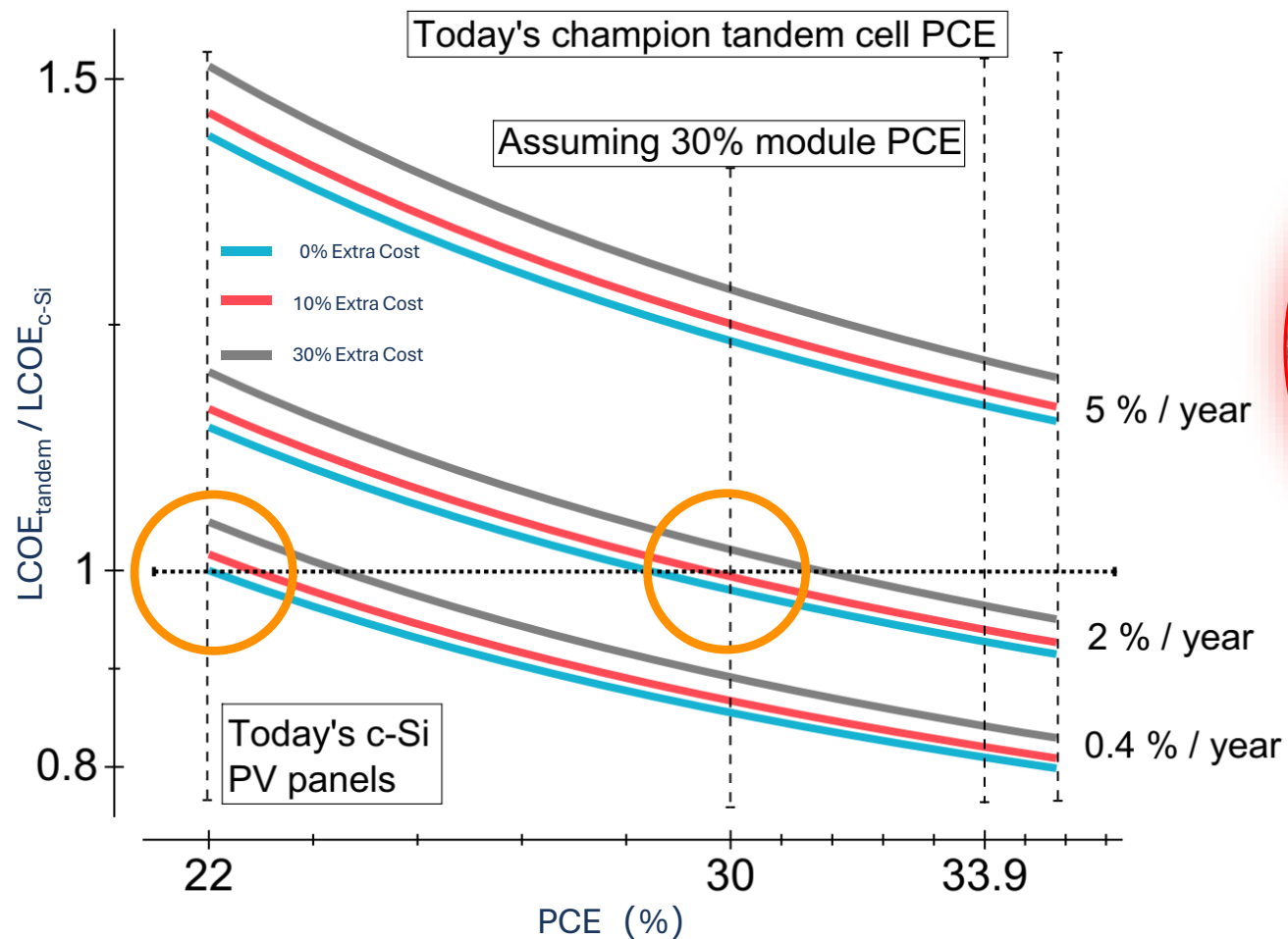
- 210mm half-cut tandem cells
- The world's first commercially-sized module with power >800 W
- The world's first commercially-sized perovskite/silicon tandem module (2384 × 1303 mm²)
- Performance verified by TÜV SÜD Certified Testing Lab

Date	Total area (m ²)	I_{sc} (A)	V_{oc} (V)	FF (%)	P_{max} (W)
Nov. 2024	3.1	7.547	135.7	78.93	808
May 2025	3.1	7.535	135.9	81.05	829
Latest Record (June 2025)	3.1	7.602	136.1	81.35	841

Technical Challenges of Perovskite Solar Cells

- Perovskite Silicon cells have demonstrated stability issues leading to excessive degradation
- Tandem modules of 30% PCE lose their LCOE advantage over silicon counterparts if the annual degradation surpasses 2%

Aydin et al., Science 383, eadh3849 (2024)



Degraded PSC modules

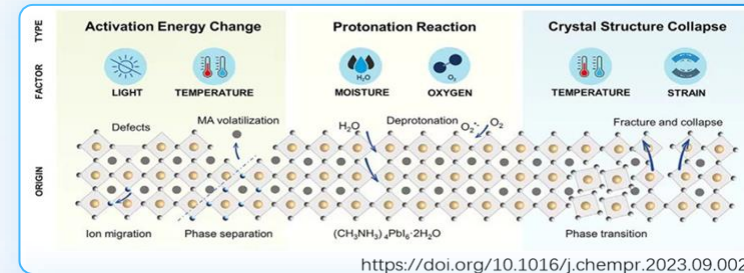
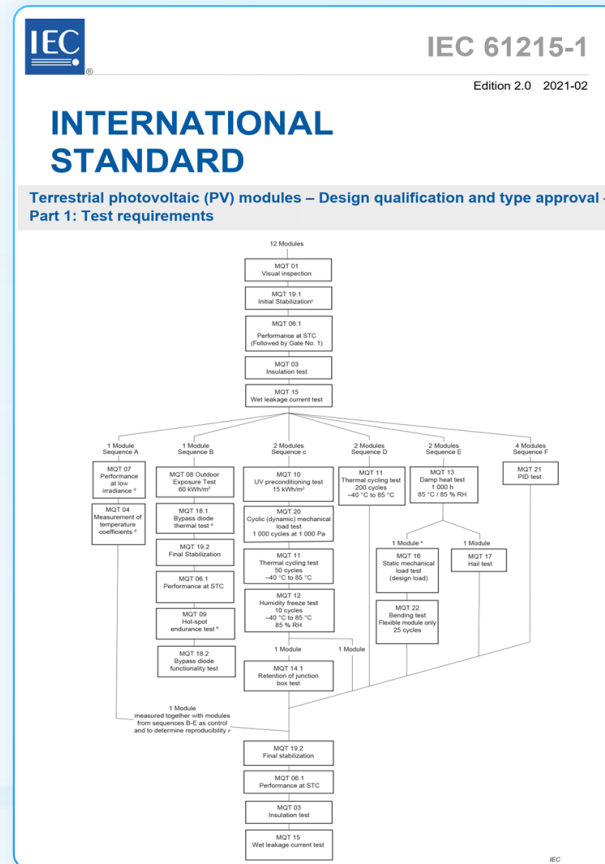


Technical Challenges of Perovskite Solar Cells

Conventional IEC 61215 testing fails to properly evaluate perovskite PV stability. Dedicated standards addressing perovskite-specific degradation pathways are urgently needed.

No proven accelerated tests + limited outdoor proof = perovskite reliability unknowns.

IEC 61215 test protocols



CONSENSUS STATEMENT

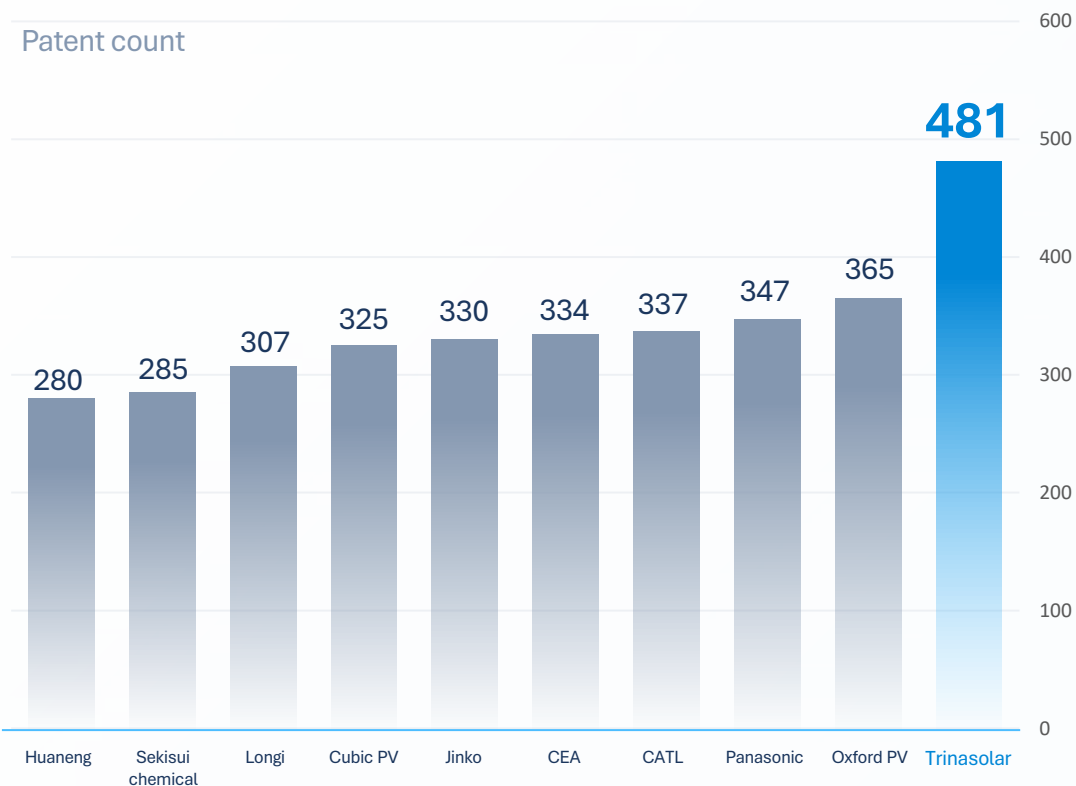
Consensus statement for stability assessment and reporting for perovskite photovoltaics based on ISOS procedures

Mark V. Khenkin^{1,2}, Eugene A. Katz^{1,3*}, Antonio Abate⁴, Giorgio Bardizza⁵, Joseph J. Berry⁶, Christoph Brabec^{7,8}, Francesca Brunetti⁹, Vladimir Bulovic¹⁰, Quinn Burlingame¹¹, Aldo Di Carlo⁹, Rongrong Cheacharoen¹², Yi-Bing Cheng¹³, Alexander Colmann¹⁴, Stephane Cros¹⁵, Konrad Domanski¹⁶, Michał Dusza¹⁷, Christopher J. Fell¹⁸, Stephen R. Forrest^{19,20,21}, Yulia Galagan²², Diego Di Girolamo²³, Michael Grätzel²⁴, Anders Hagfeldt²⁵, Elizabeth von Hauff²⁶, Harald Hoppe²⁷, Jeff Kettle²⁸, Hans Köbler⁴, Marina S. Leite^{29,30}, Shengzhong (Frank) Liu^{31,32}, Yueh-Lin Loo^{11,33}, Joseph M. Luther⁶, Chang-Qi Ma³⁴, Morten Madsen³⁵, Matthieu Manceau¹⁵, Muriel Matheron¹⁵, Michael McGehee^{6,36}, Rico Meitzner²⁷, Mohammad Khaja Nazeeruddin³⁷, Ana Flavia Nogueira³⁸, Çağla Odabaşı³⁹, Anna Osherov¹⁰, Nam-Gyu Park⁴⁰, Matthew O. Reese⁶, Francesca De Rossi^{9,41}, Michael Saliba^{42,43}, Ulrich S. Schubert^{27,44}, Henry J. Snaith⁴⁵, Samuel D. Stranks⁴⁶, Wolfgang Tress⁴⁷, Pavel A. Troshin^{47,48}, Vida Turkovic³⁵, Sjoerd Veenstra²², Iris Visoly-Fisher^{1,3}, Aron Walsh^{49,50}, Trystan Watson⁴¹, Haibing Xie⁵¹, Ramazan Yildirim³⁹, Shaik Mohammed Zakeeruddin²⁴, Kai Zhu⁶ and Monica Lira-Cantu^{51*}

Consensus ISOS testing procedures

IP Leadership and Collaboration

Trinasolar leads the world with **481** patent applications and has established a key strategic intellectual property collaboration with Oxford PV.



*Statistical analysis of global perovskite solar cell invention patents (consolidated by application number) published between April 1, 2015, and March 31, 2025, based on IPRdaily data.

Oxford PV, Trina Solar enter patent licensing agreement for perovskite-silicon tandem solar

The exclusive license agreement covers the manufacture or sale of perovskite PV products for the Chinese market. A statement from Oxford PV says the agreement “underscores the industry consensus that perovskite-based PV technologies are the future of solar.”

APRIL 9, 2025 **PATRICK JOWETT**

- LEGAL
- MANUFACTURING
- MARKETS
- MODULES & UPSTREAM MANUFACTURING
- TECHNOLOGY
- TECHNOLOGY AND R&D
- CHINA



Summary

- TOPCon Ultra offers cell efficiency increases >1.0% and power increases >30W
- Tandem cells raise practical cell efficiency maximum to 37.76%
- Perovskite + silicon tandem cells offer the highest-efficiency and most cost-effective solution among tandem cell combinations
- Trinasolar's 210mm half-cut tandem cells set consecutive cell-efficiency records of **31.1%** and **32.2%**
- Trinasolar broke the 30% module efficiency barrier with a certified module efficiency of **30.6%**
- Trinasolar unveiled the world's first commercially-sized perovskite/silicon tandem module to surpass 800W, achieving certified power outputs of **808W**—now further improved to **841W**.
- Key challenges for perovskite tandems: Stability & Standardization
- Trinasolar leads the way in tandem perovskite IP through patents and partnerships



A Global Leader in Smart Energy Solutions for Solar & Storage

