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Driving innovations in photovoltaics for highest performance and lowest LCOE

21.08.2018, Swiss-US Energy Innovation Days 2018; André Richter; Meyer Burger Technology AG

Meyer Burger drives technology and productivity

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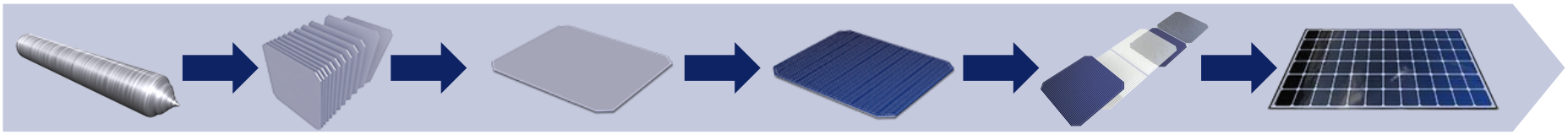
Wafer
Ingot to Wafer

Cell
Wafer to Cell

Module
Cell to Module



Diamond Wire Saw

DW 288 Series 3

Wafer Inspection

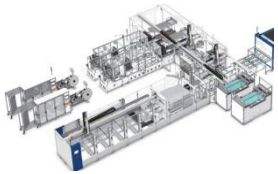
WIS-06

Cell coating

SiNA

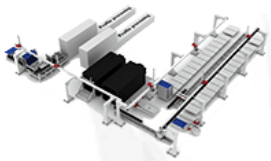
MAiA

Module Line



SWCT

Module Testing



HighLIGHT by Pasan

Industry Standard:

	«DW288»	«WIS»	«MB PERC»		«SWCT»	«Pasan»
# tools	> 150	> 142	> 500	> 140	> 5	> 100
Installed Capacity	>7GW	>23GW	> 30 GW	> 18 GW	> 320 MW	> 20 GW
Market Share:	~35%	~80%	> 30 %	> 90%	Increasing	> 80%

Holistic Approach
to lower the cost of kWh

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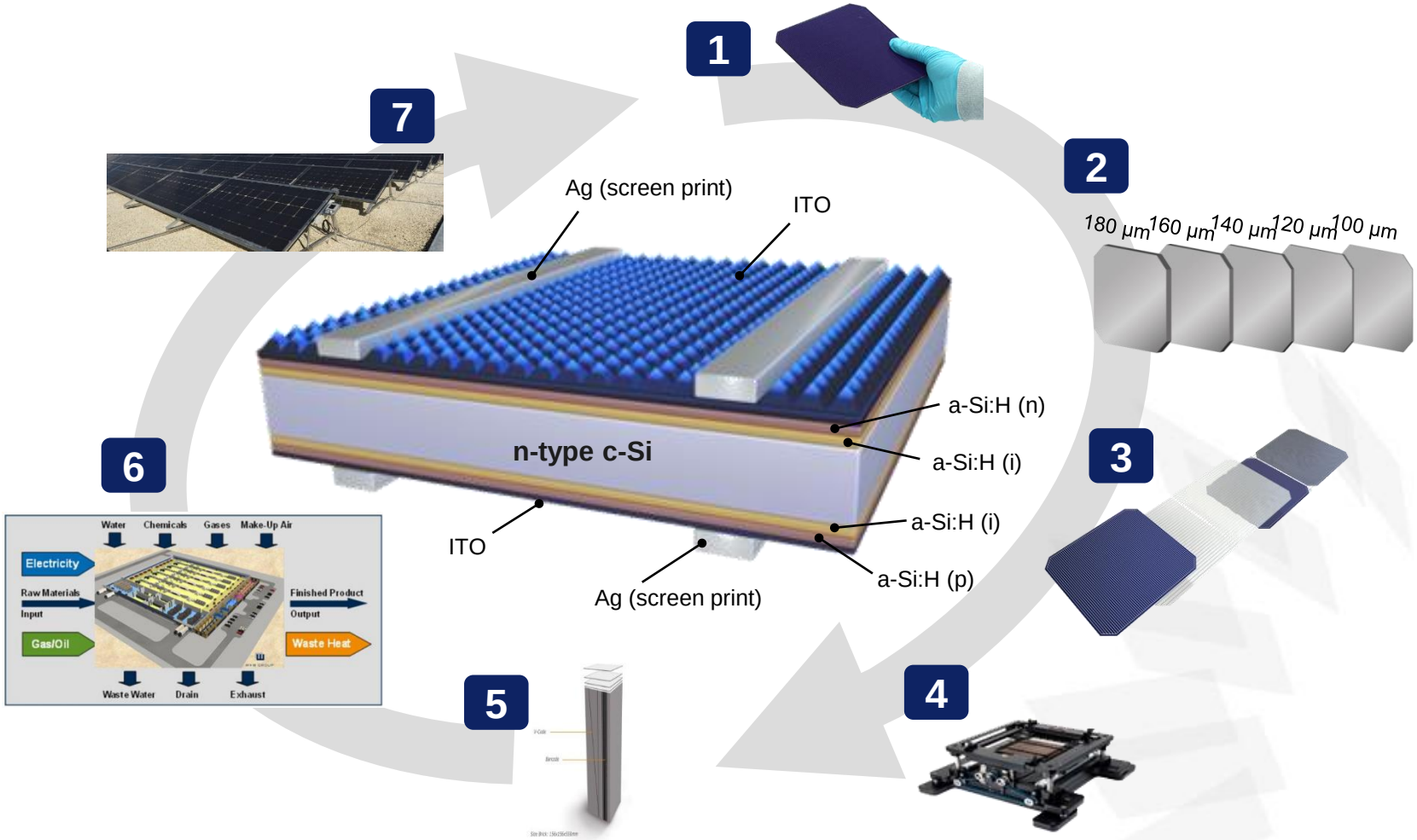
➔Lower Production Costs ➔Higher Efficiency ➔Higher Yield ➔Increased Longevity



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p-Si Passivated Emitter Rear Contact (p-PERC)

Improved productivity with MAiA6.1, DiVA6.1 and FABiA4.1 for mono and multi

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-1 Tool

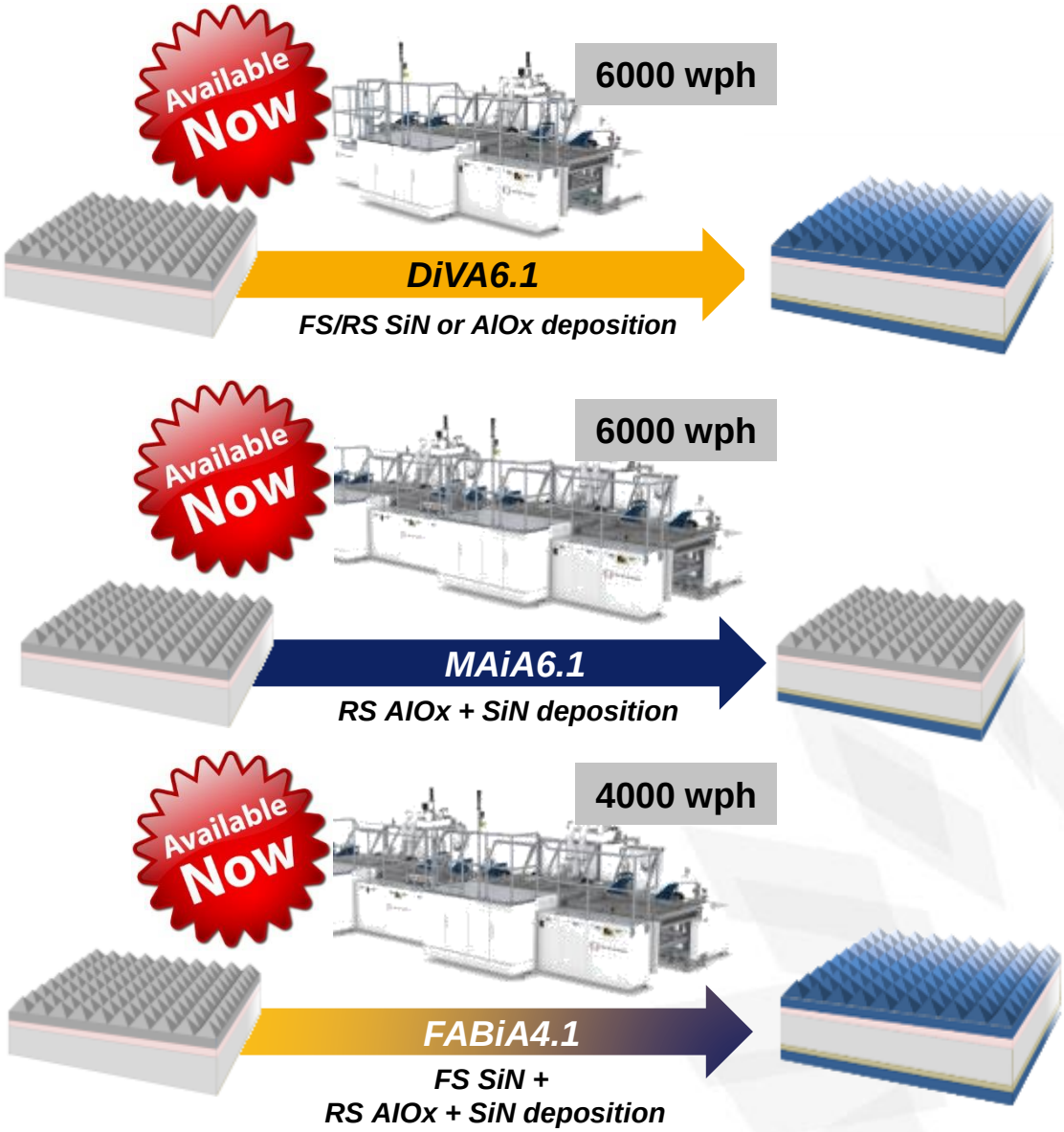
Reduces PERC process steps from 11 to 10 (ALD used for AlOx) vs. use of Tube-CVD RS/FS

-1 tool

Reduces PERC process steps from 11 to 10 vs. use of ALD and Tube-CVD RS/FS

-2 tools

Reduces PERC process steps from 11 to 9 and increases cell performance



Evolutionary p & n-type approaches towards passivated contacts based on MAiA tunnel oxide and doped silicon layers

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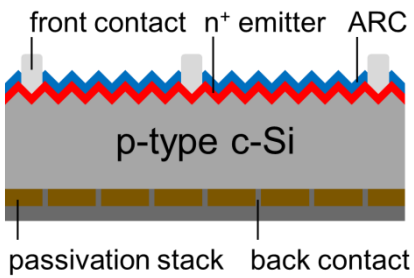
csem

n-doped a-Si after crystallization
eff. Lifetime = 1054µ iVoc = 725mV

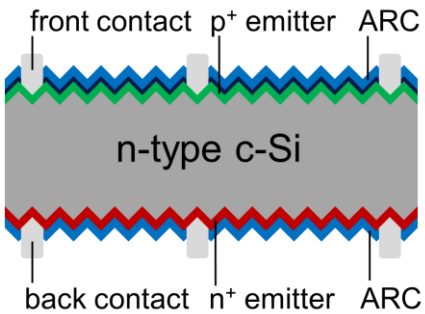
Rsheet = 50 +/- 2 Ω/sq (after crystallization)
Thickness = 180nm (as deposited)

SERIS



p-PERC

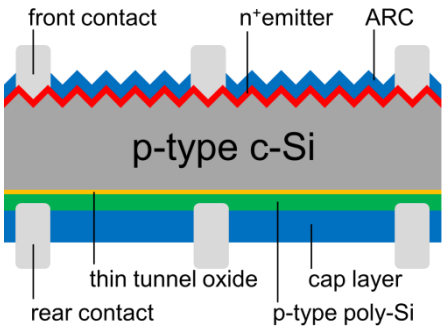
Meyer Burger MAiA inline PECVD process flexibility:
rear / front passivation + **ARC** + **tunnel oxide** + **doped silicon** + **cap layer**

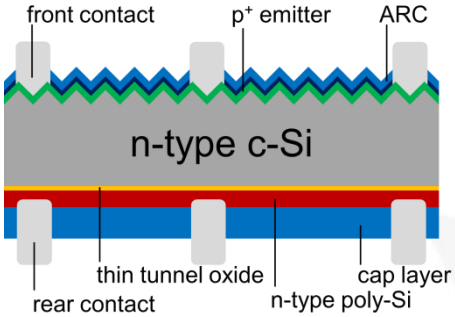


n-PERT

Rear Tunnel Oxide

p doped rear a-Si





Rear Tunnel Oxide

n doped rear a-Si

- MB provides technology concepts and deposition equipment for nPERT and pPERC with passivated contacts on cell back side
- ARC layer, passivation layer as well as tunnel oxide and doped silicon layer deposition for passivated contacts applied with MAiA

CoO and performance of MAiA, FABiA vs. ALD AlOx and PECVD Tube SiNx

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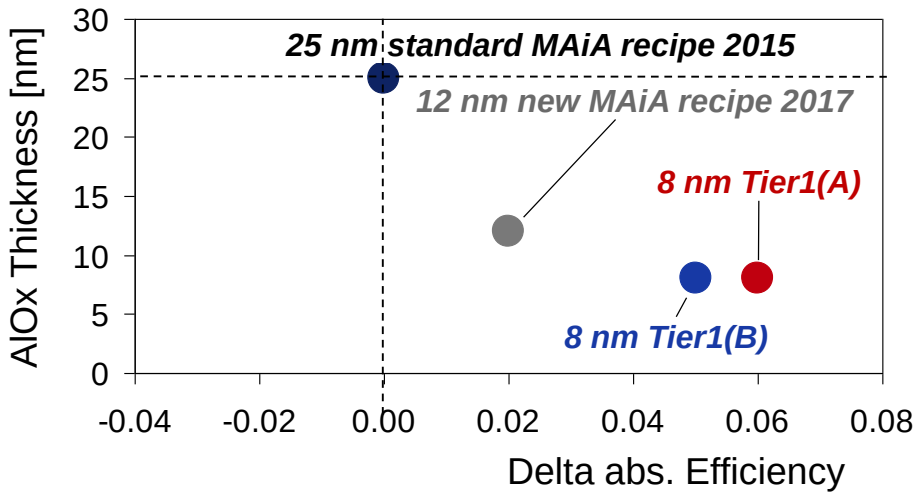
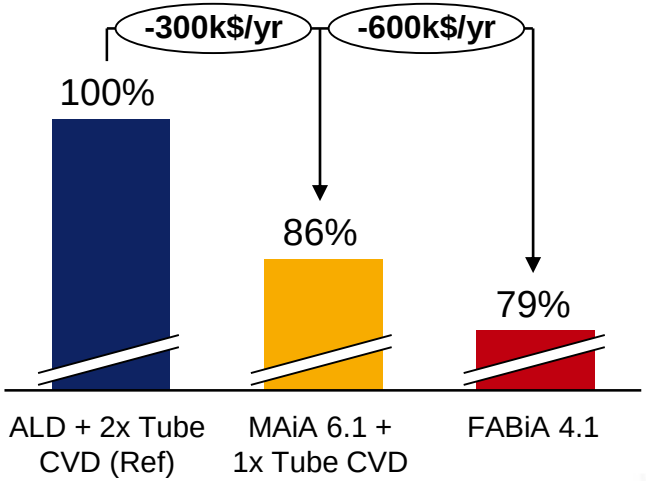
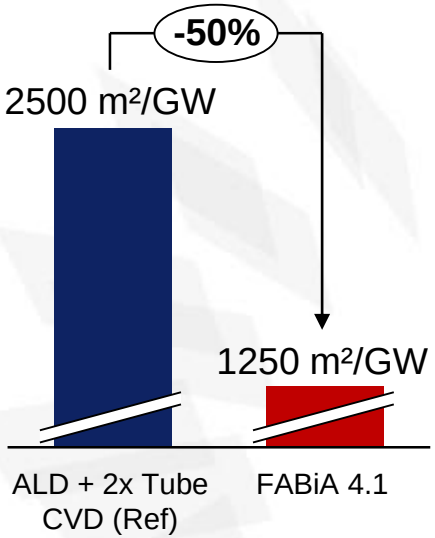




- Standard recipe 12 nm MAiA AlOx
- Tier 1 customers moving to 8 nm MAiA AlOx with efficiency gain
- TMA consumption lower than ALD at similar thickness
- -50% less fab space required for ALD + 2x CVD tube (FS/RS SiNx) vs. FABiA 4.1
- Total cost of ownership for MAiA 6.1 and FABiA 4.1 -15% and -20% lower than ALD + tube CVD
- Preventive maintenance reduced to 5h
- Customers w/o emitter oxidation can use a plasma oxide integrated in MAiA/FABiA achieving +0.1%-0.2% abs. CE gain
- ROI of higher capex payed back by OPEX savings in <1yr



Meyer Burger also driving PERx power roadmap evolutionarily using MAiA®

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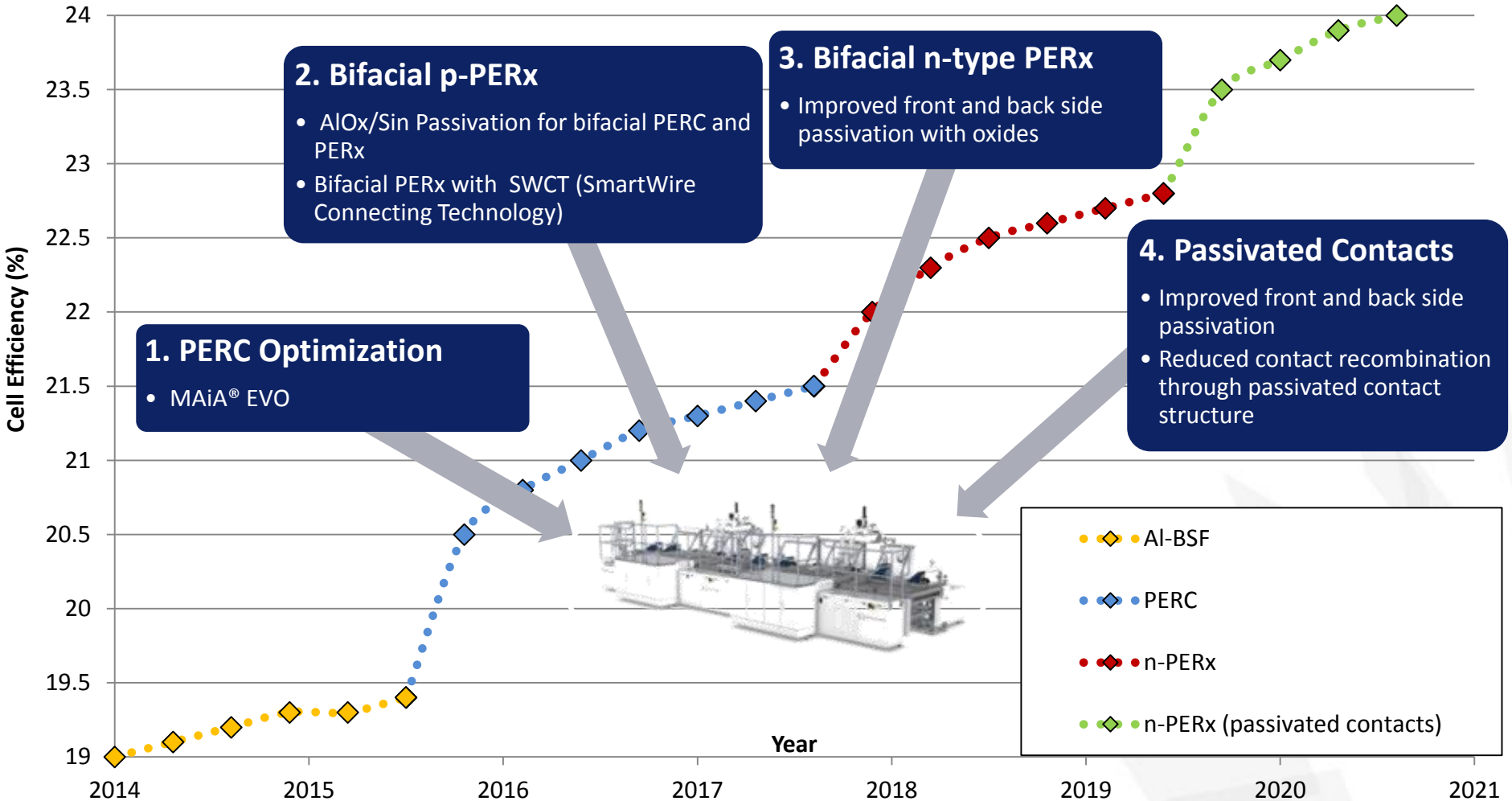
csem

SERIS



1. PERC Optimization

- MAiA® EVO

2. Bifacial p-PERx

- AlOx/Sin Passivation for bifacial PERC and PERx
- Bifacial PERx with SWCT (SmartWire Connecting Technology)

3. Bifacial n-type PERx

- Improved front and back side passivation with oxides

4. Passivated Contacts

- Improved front and back side passivation
- Reduced contact recombination through passivated contact structure

MAiA® = Multi Application inline Apparatus – Highly flexible concept

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Heterojunction Technology (HJT)

Long history for HJT:

Meyer Burger industrialises cost competitive 6'' technology

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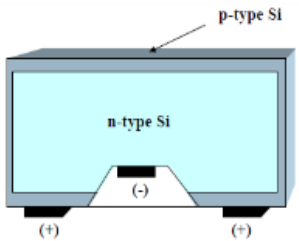
Meyer Burger Germany has been involved since 2008 with 6'' wafer technology

Development Phase



1954 **Bell Labs, US:** First c-Si solar cell, n-type, IBC, monofacial, 6% efficiency

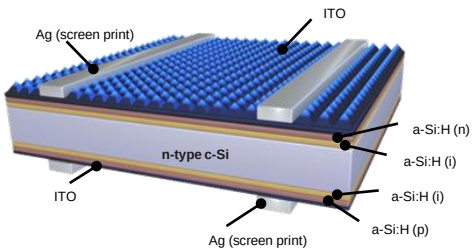
1964 **RCA Labs, US:** Theory of HJT cells, S.S. Perleman

1978 **a-Si thin film deposition** PECVD development starts

1981 **Sanyo, JP:** First HJT solar cell, 5'' wafer technology

1991-1994 **Sanyo, JP:** a-Si solar cell and its manufacturing patented

First Mover



2001 **Sanyo, JP:** 1st HJT module on market, n-type, 5'' wafer technology

2004 **Oerlikon Solar, CH:** First large area a-Si production equip. (on glass)

2006-2009 **EPFL/CSEM, CH: Prof. Ballif** Thesis on HJT cells

2008 **Meyer Burger** (formerly Roth&Rau): R&D center for HJT, Neuchâtel, CH

2009 **CEA/INES, FR:** Lab-Fab for HJT

Industrialisation Phase

2009 **Panasonic, JP:** Acquires Sanyo

2012 **Panasonic, JP:** Champion cell 24% HJT cell, 5'' wafer technology

2015 **Meyer Burger:** Production line in Hohenstein-Ernstthal, DE

2016 **Kaneka, JP:** World record for single junction: 26.6%, IBC-HJT cell, 6'' wafer technology

2017 **Meyer Burger:** Record 335 Watt module (60 cells) based on industrialised 6'' (M2) HJT technology

HJT – Industrialized at Meyer Burger

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24.02%
highest cell efficiency

23.7%
average efficiency

335W
module power (monofacial)

92.8%
bifaciality

Fraunhofer ISE
CalLab PV Cells

TÜVRheinland

- ~3 million HJT cells produced
- Production CE 23% BB0 (22.3% 5BB)
- Overall yield proven at 98.5% (mechanical, electrical, optical)
- CAPEX significantly reduced
- -25% less footprint than PERx
- 120 µm wafer capability unlike PERx

Result achieved:
HJT / SWCT 72 cell module

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410 W

72 M2 cells
White Back Sheet

Meas. at	P_{max} [W]	V_{mp} [V]	I_{mp} [A]	V_{oc} [V]	I_{sc} [A]	FF [%]
MB	**412**	44.7	9.2	53.0	9.8	79.7%
CEA	**413**	45.6	9.1	53.8	9.6	80.2%

Average cell η: 23.4%

90% bifaciality:
With 20% rear side albedo ca. 480W

liten cea tech

ines INSTITUT NATIONAL DE L'ENERGIE SOLAIRE

CoO of HJT continues declining (OPEX)

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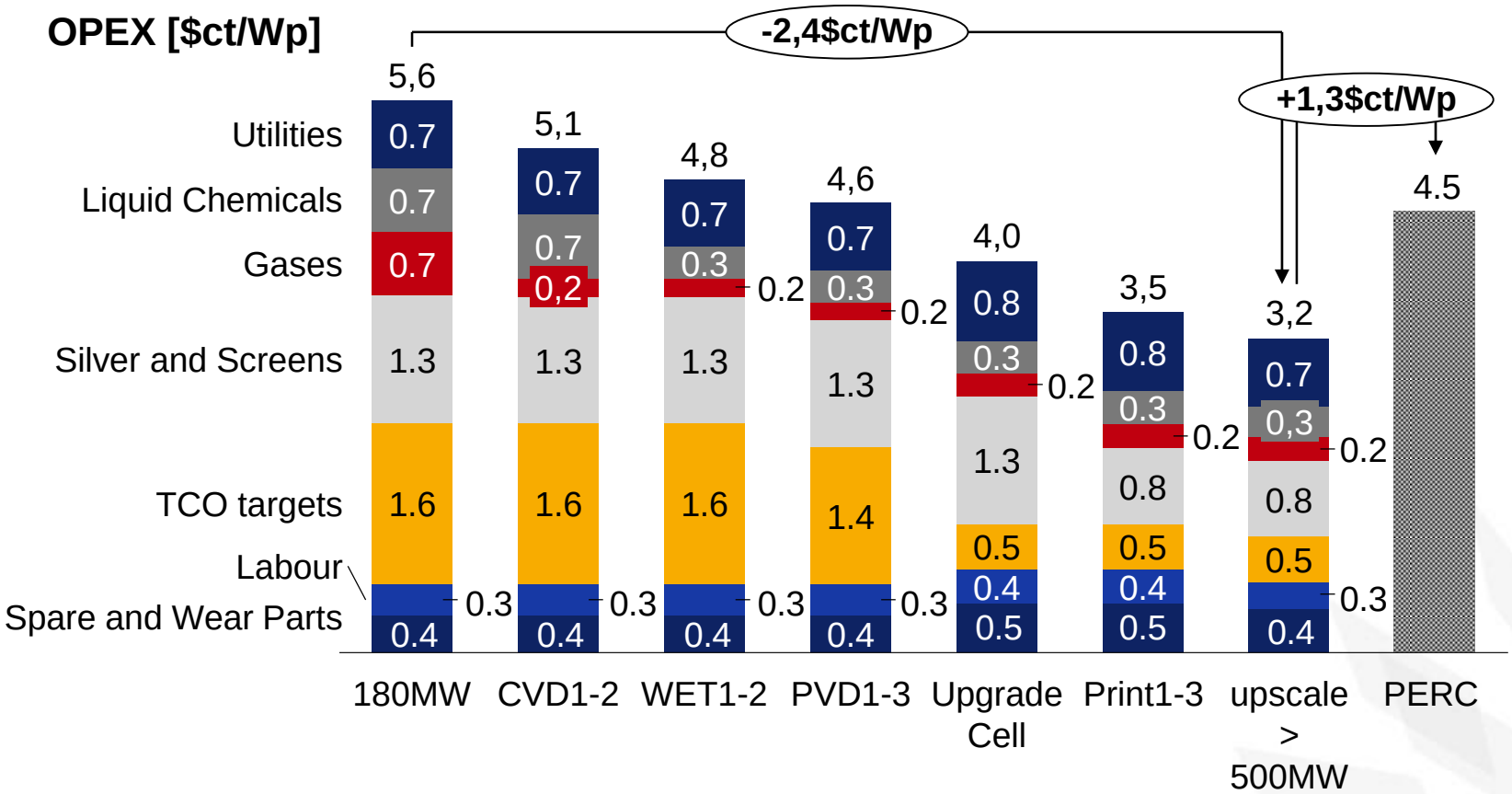

- OPEX with 3.2$ct/Wp at >500MW capacity
- CAPEX reduced
- Total cost of ownership at 6.0$ct/Wp in 2022

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SmartWire Connection Technology (SWCT)

Evolution of Cell Connection Technology

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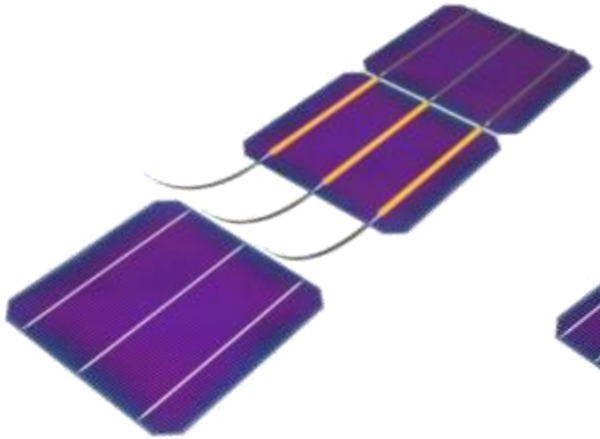
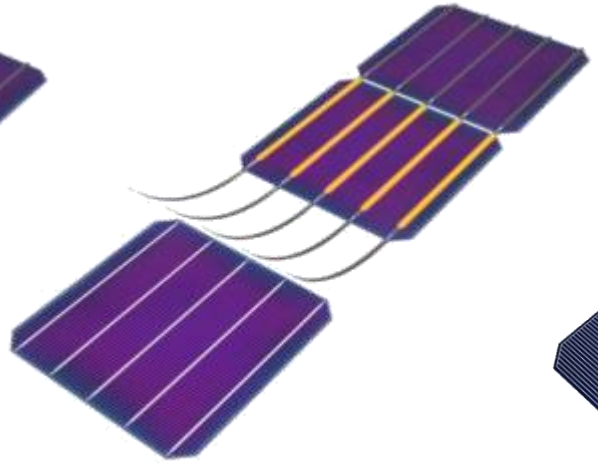
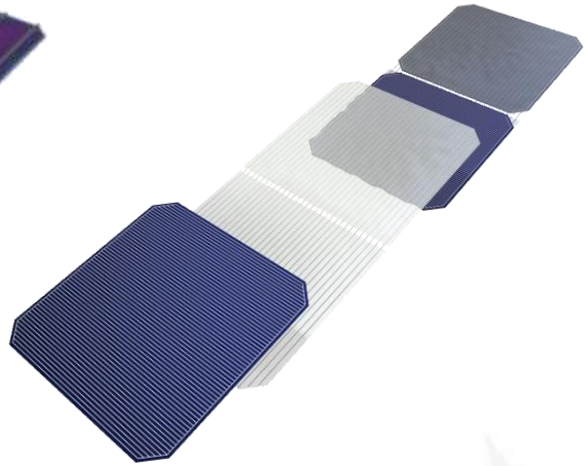


Cell with 3 Busbars



Cell with 5 Busbars



+10..15W

Cell with SWCT

Towards higher module power output (+10..15W with SWCT)

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Energy Yield

Energy yield monitoring of Meyer Burger HJT vs. other cell technologies

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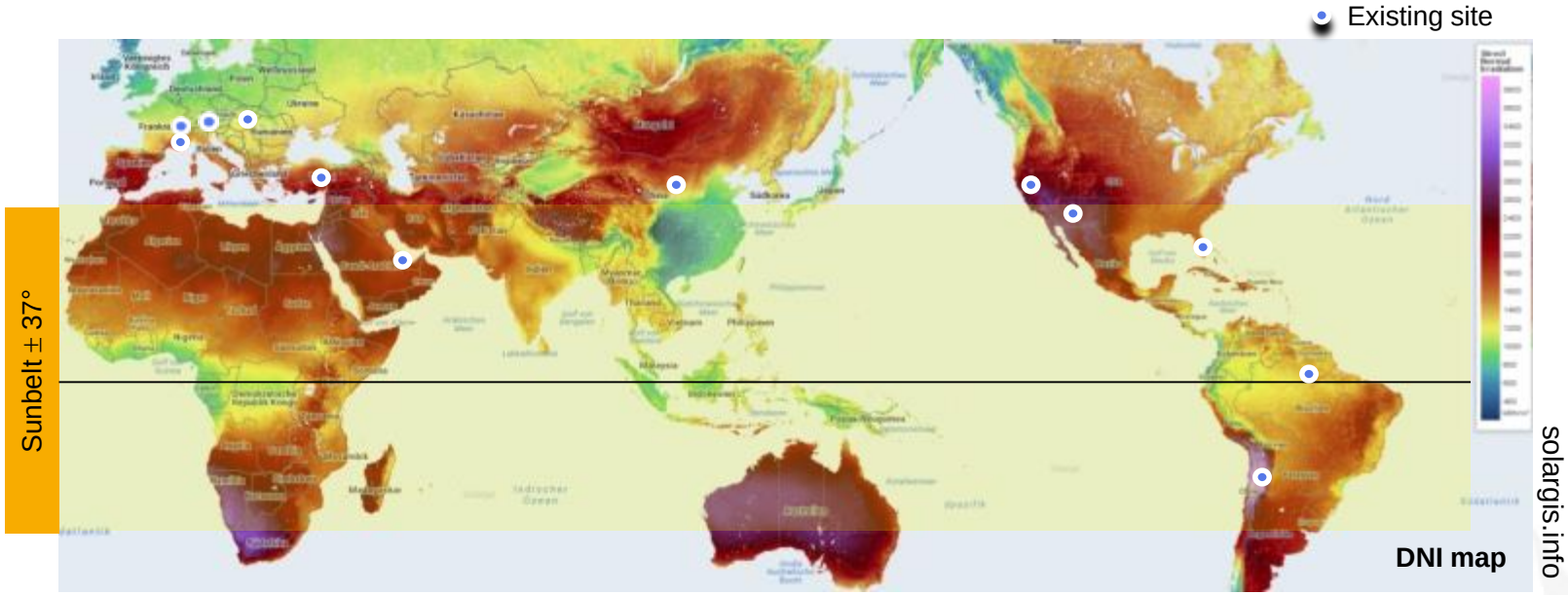

MB owned sites, high accuracy:

- UAE, Abu Dhabi: fixed tilt (8pcs)
- US, California: 1-axis tracking (8pcs)
- US, Arizona: fixed tilt (2pcs)
- US, Arizona: 2-axis tracking (2pcs)
- China, Yinchuan fixed tilt (8pcs)

Reporting MB technology figures:

- France, institute Chambéry (>20pcs, strings)
- France, institute Cadarache (>20pcs, strings)
- Hungary, company (4pcs)
- Chile, university (6pcs)
- Brazil, company (36pcs, strings)
- US, Miami, company (8pcs)
- Turkey, university (1pcs)
- Switzerland, university (20pcs, strings)

HJT/SWCT
with superior energy yield

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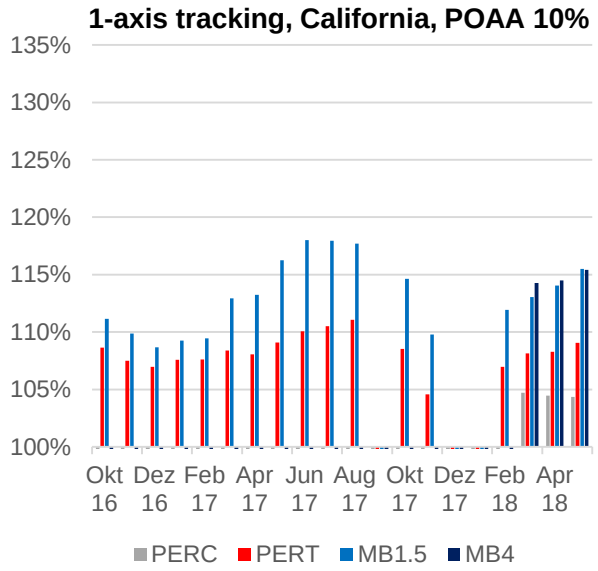
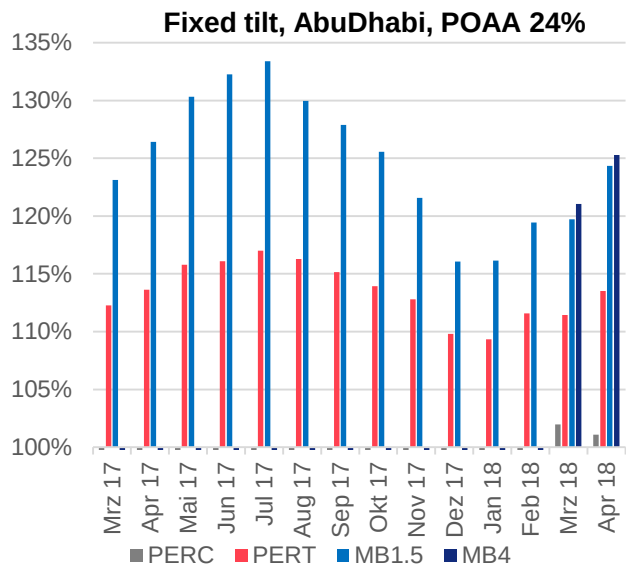
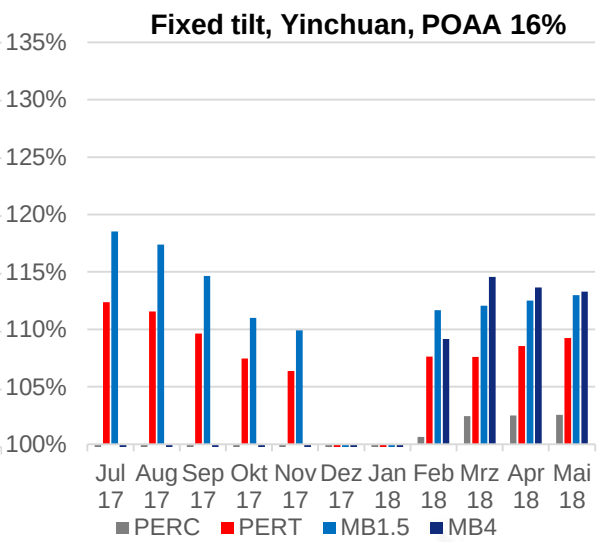
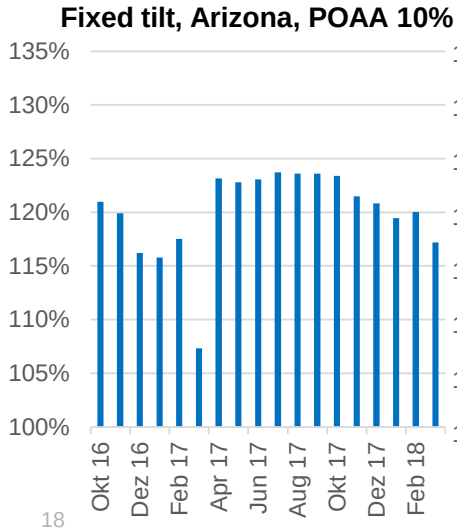
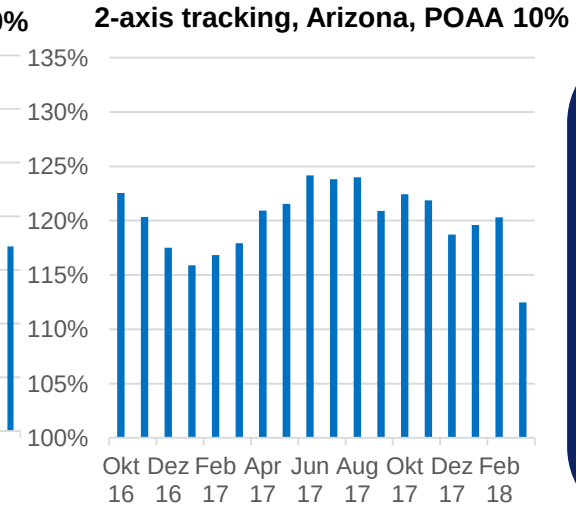




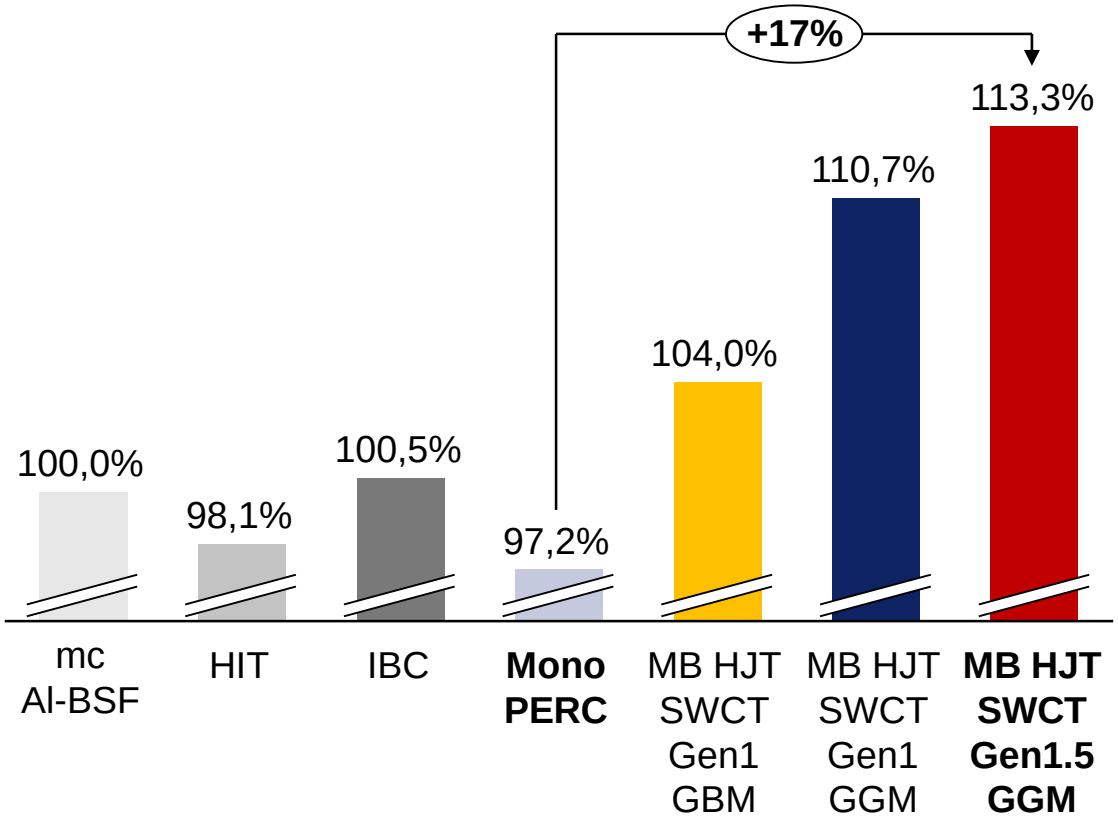






- Bifacial HJT/SWCT modules have a monthly average of **around 10-25% more energy yield**
- Bifacial HJT/SWCT modules have **highest yield of all tested technologies** (PERT, PERC, Al-BSF)
- Bifacial **yield increases with increased diffuse light**
- HJT/SWCT **yield advantage increases with higher temperatures**
- HJT/SWCT generation 4 **increases energy yield**
- **All figures referenced to kWh/kWp and to monofacial Al-BSF technology**

kWh/kWp yield data 1/2017 – 12/2017 Middle Europe (CEA INES)



MB HJT/SWCT Gen1.5 contains still PET electrode cutting off UV and reducing performance – currently Gen4 in the works with much better UV transmission

MB HJT/SWCT outperforming any other cell concepts in terms of kWh/kWp such as

- mc Al-BSF
- HIT
- IBC
- Cz PERC

Source: CEA INES

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Levelized Cost of Electricity (LCOE)

Manufacturing step cost outlook 2022

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Wafer/pc	$0.45	$0.48	$0.48
P Cell	5.52W (22.7%)	5.78W (24.0%)	6.05W (24.8%)
P Module	**325W**	**340W**	**355W**

Step	Cz pPERC $ct/Wp	Cz n-PERx $ct/Wp	Cz n-HJT $ct/Wp
Wafer	8.3	8.3	7.9
Cell	6.7	6.4	6.0
Module	9.0	8.5	8.1
Total	**24.0**	**23.2**	**22.0**

- „Standard“ Cz pPERC (as well as multi PERC) will be the next commodity and under attack by 2022 as evolutionary concepts will take over (e.g. Passivated Contacts, TOPCON).
- HJT because of power, cost and LCOE ideal for green field

M2 wafer format
Wafer ASP $0.45/pc for p
Wafer ASP $0.48/pc for n
ASP reduction -5%/yr

Cell step costs include additional process steps needed for n-PERx (e.g. Passivated Contacts) but overall decrease

Module BoM decreasing by historical avg. -6%/yr

Bifaciality and ½ cell not considered, ref 60c M2

CTM slightly reduced

High efficiency

→ less space → lower installation costs

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Example for Sunbelt: 1,600 kwh/m², 50° C

Savings of **22%** or 7,500 m²

Standard PV System
Example: 34,000 m²

Picture: google earth

MB HJT PV System
Example: 26,500 m²

1.8 MW PV system with **standard modules**

- 7,500 modules (240 Wp)
- Total cost of **1,134 USD/kWp** (*)
- 2,100,000 kWh/a

1.8 MW PV system with **HJT modules**

- 5,790 modules (311 Wp)
- Total cost of **1,098 USD/kWp** (**)
- 2,250,000 or 2,550,000 kWh/a

(*) Typical worldwide market price for standard module, w/o financing costs or land costs.

(**) HJT modules produced with margin (Cost of Ownership based on Meyer Burger assumption), w/o financing costs or land costs.

LCOE HJT vs. other cell technologies

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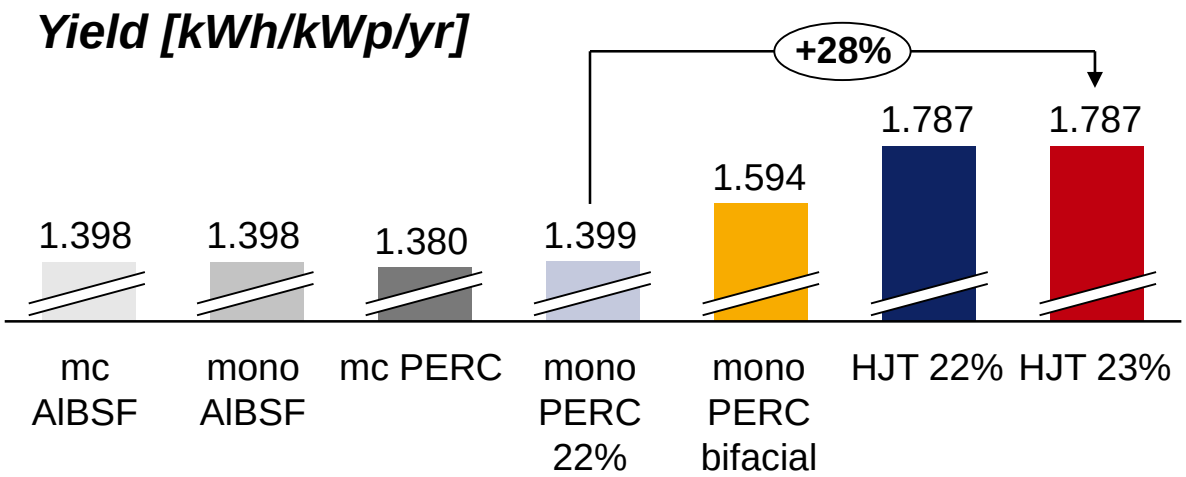

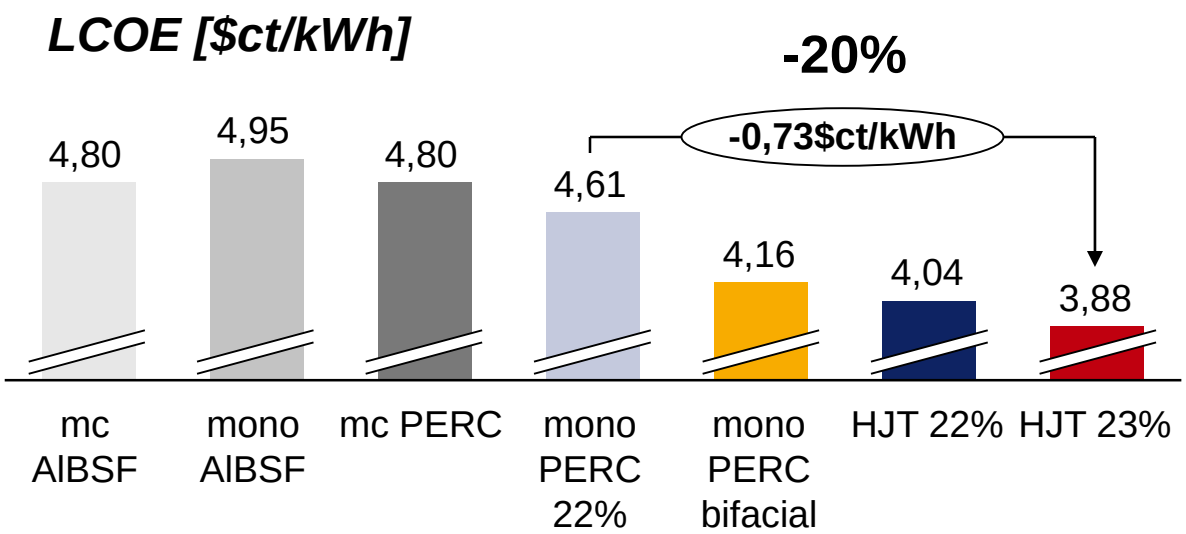

HJT leads to lowest LCOE

- Lowest Tc
- Energy generation cost at cheapest level
- Upside potential due to high efficiency potential

Assumptions

- 1,600 kWh/m^2 yearly irradiation
- 55°C average module working temperature
- 1% LID for PERC
- 20% albedo effect for bifacial modules

Decreasing LCoE opens new competitive markets w/o subsidies

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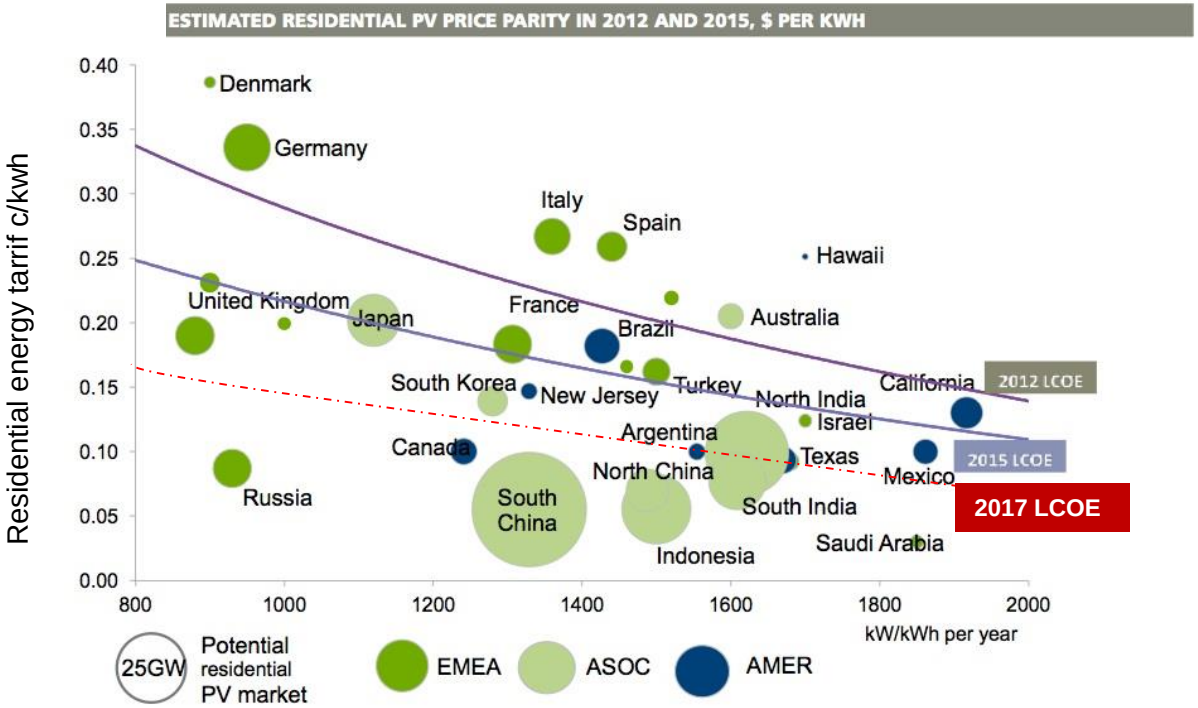

LCOE based on 6% weighted average cost of capital, 0.7%/year module degradation, 1% capex as O&M annually. $2.65/W capex assumed for 2012.

Source: Bloomberg New Energy Finance

- Decreasing LCoE of PV Systems allow more and more markets (characterized by various radiation levels, energy tariff levels) to become competitive
- PV self production (decentralized systems) becomes cheaper than grid-based power supply
- **Lower LCOE enables new markets adapting PV as cost competitive energy source**
- **New markets scale in absence of subsidies**, mainly constrained by project financing requirements

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Outlook

Technology outlook 2018..2022

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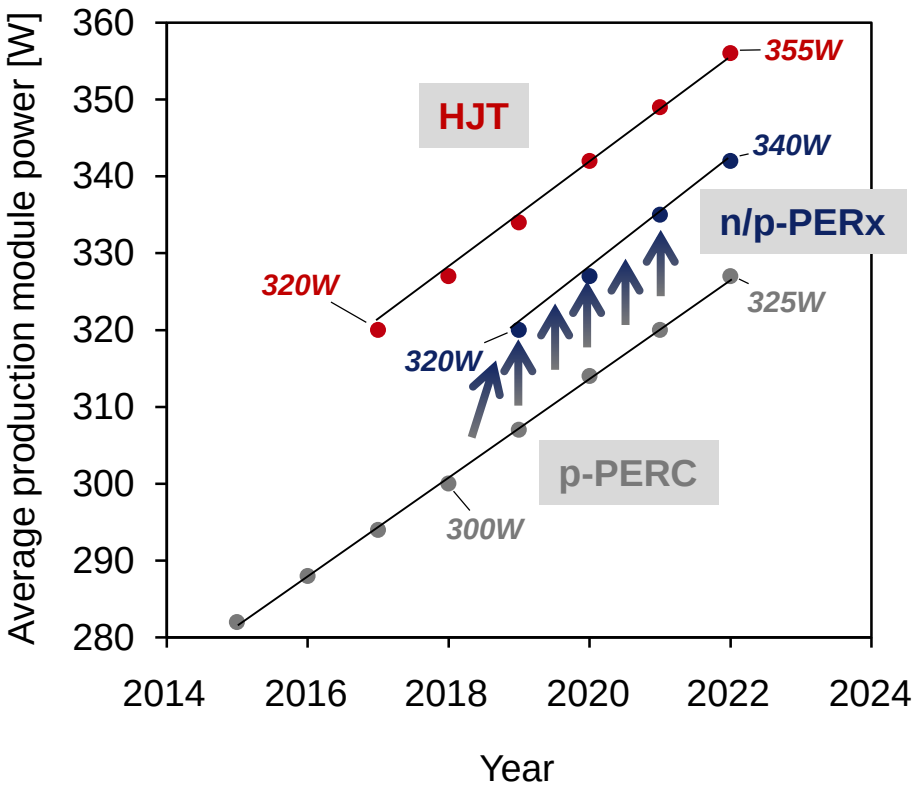


UPGRADE: Average production* PERC module power by 2022
325W

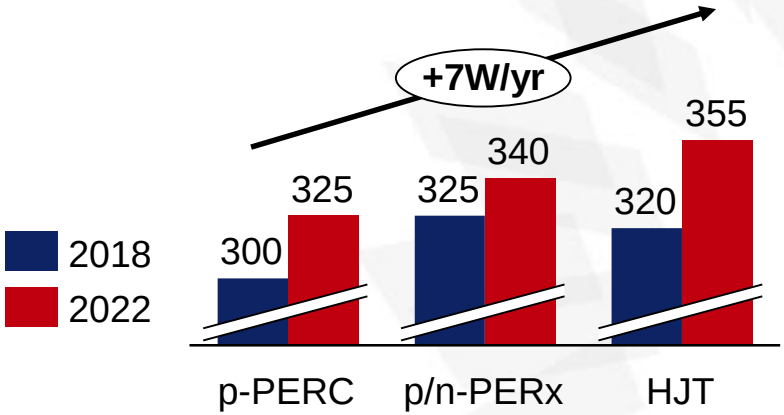
GREEN FIELD: Average production* HJT module power by 2022
355W

UPGRADE: Average production* advanced n/p-PERx module power (+15W) by 2022
340W

** Module power calculated at M2 wafer format , 60 full cells and glass-white backsheet*
Sources: Solarmedia Ltd. 2018, Meyer Burger Technology

Average production CE 2018..2022

21.0%..22.7% (2022) p-PERC (5BB ref)
22.0%..24.0% (2022) p/n-PERx (5BB ref)
22.3%..24.8% (2022) n-HJT (5BB ref)



LCOE cent€/kwh Roadmap

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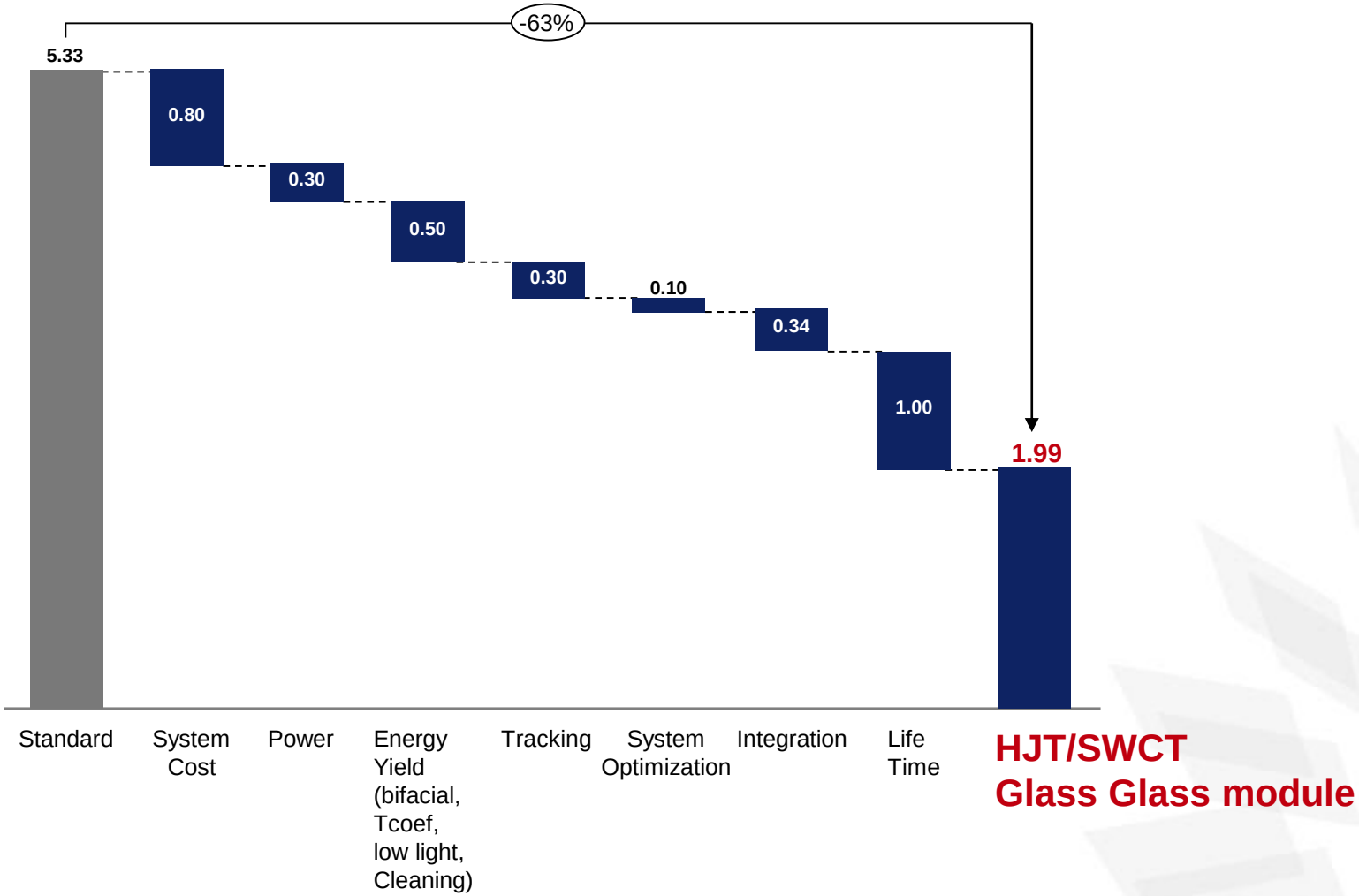

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Thank you for your attention.