VON ARDENNE

Challenges for HJT, TOPCon, IBC: Views from a German Vacuum Equipment Manufacturer

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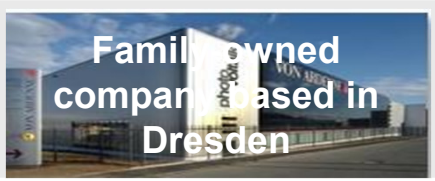
Vice President Photovoltaics

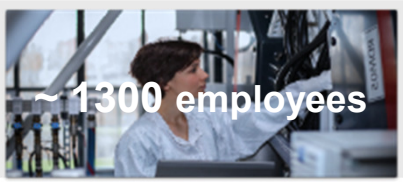
BCworkshop2023

11th Workshop on Back Contact Solar Cell and Module Technology

COATING COMPETENCE FOR GLOBAL MARKETS

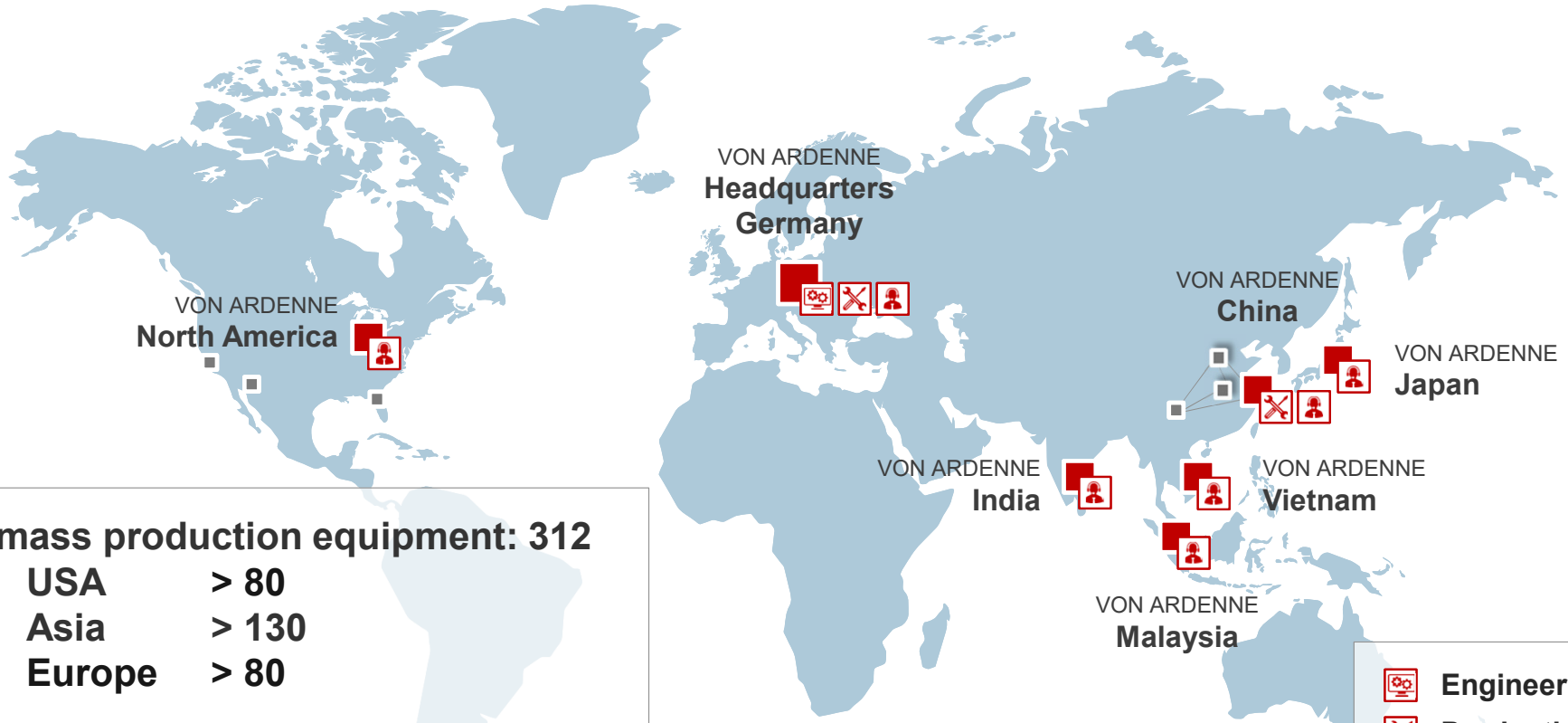
Energy - Mobility - Connectivity





Solar Cells & Modules	Turbine Blades
Smart Glass & Touch Displays	Architectural Glass
Automotive Glass	Batteries
Optics & Electronics	Fuel Cell & Electrolyzers
Advanced Driver Assistance Systems	ECO-Friendly Packaging

VON ARDENNE – A GLOBAL COMPANY



PV mass production equipment: 312

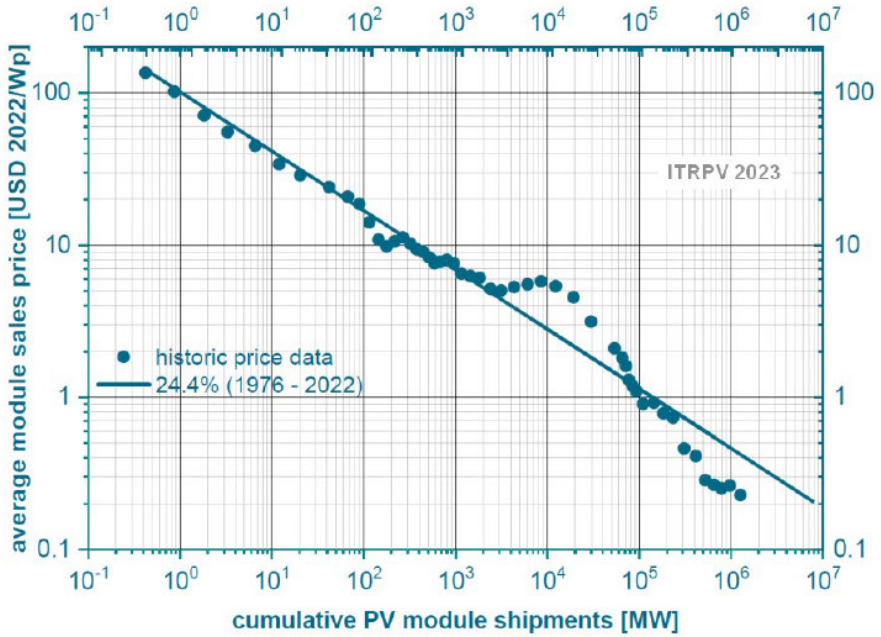
USA	**> 80**
Asia	**> 130**
Europe	**> 80**

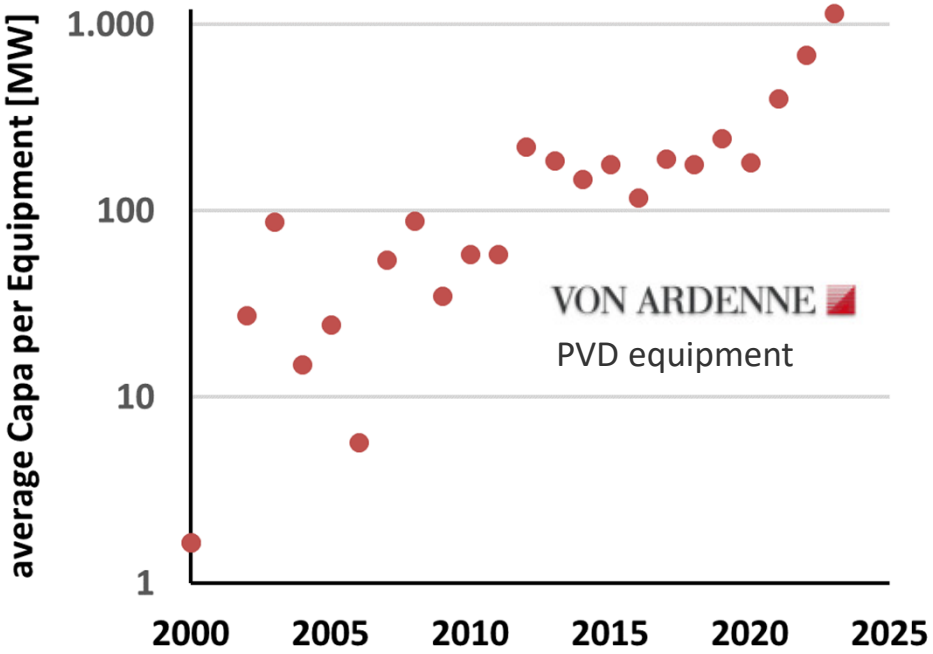
N-type cell technology > 35 GW
Thin-film photovoltaics > 37 GW

> 180 R&D and Pilot systems

VON ARDENNE – PRODUCTIVITY PER EQUIPMENT INCREASED TO > 1GW

Contribution of equipment manufacturing on reduced module prices



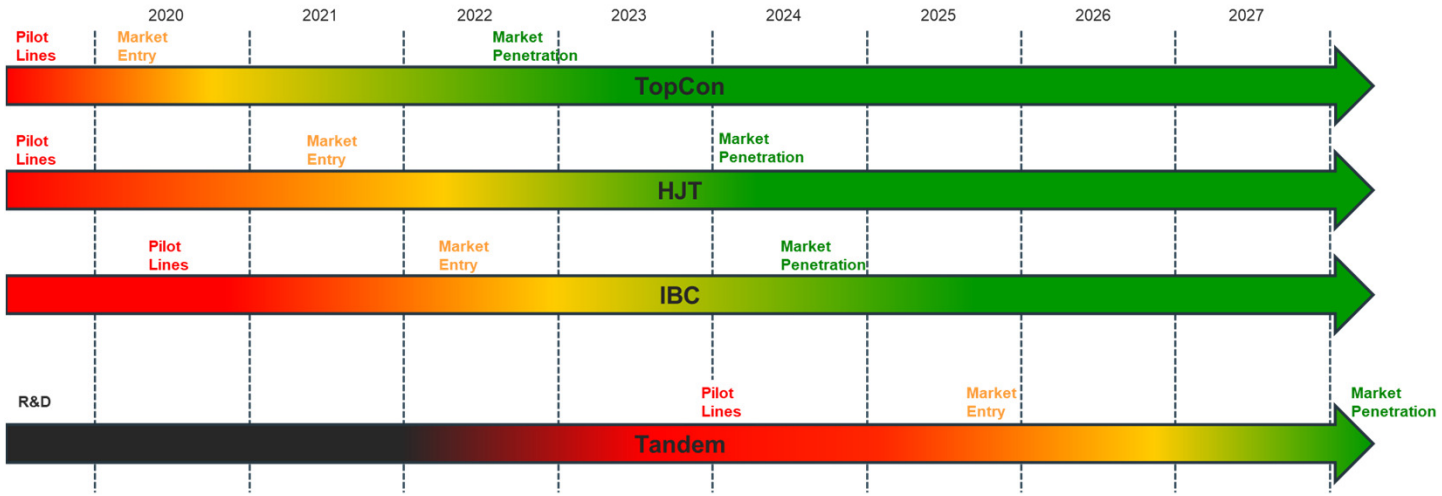


In last 46 years, module price dropped by ~ 1000

In last 23 years, productivity increased by ~ 1000

VON ARDENNE SERVES DIFFERENT AREAS IN THE FIELD OF TECHNOLOGY AND SCALING

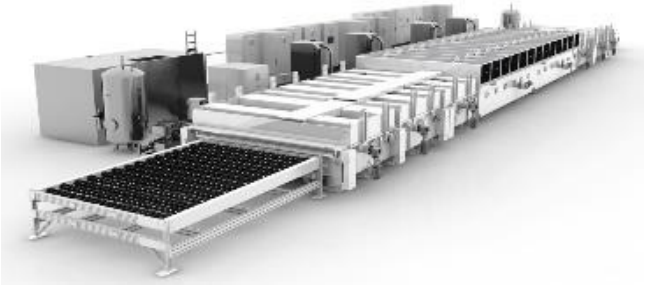
	Capacity
R&D	< 50 MW
Pilot Lines	< 300 MW
Market Entry	~ 1 GW
M. Penetration	> 5 GW



VON ARDENNE‘s Equipment Plattforms for PVD coatings (Magnetron Sputtering & Evaporation)

HISS
Lab - 100 MW

XEA|nova
200-700 MW

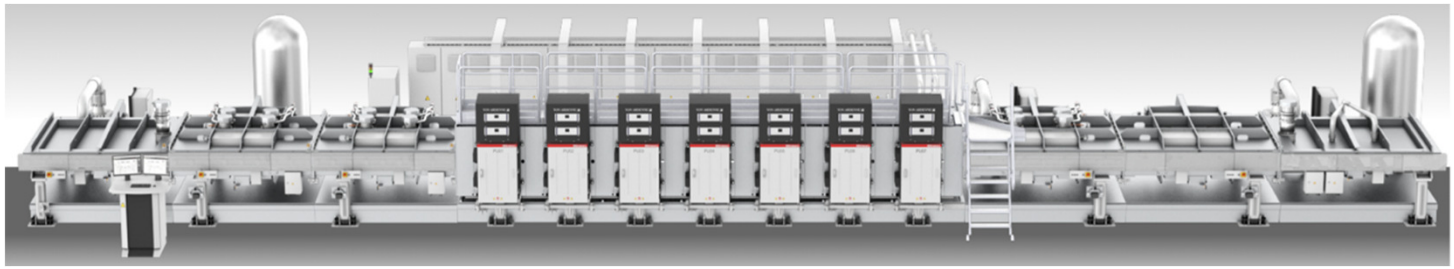


GIGA|nova
900-1300 MW

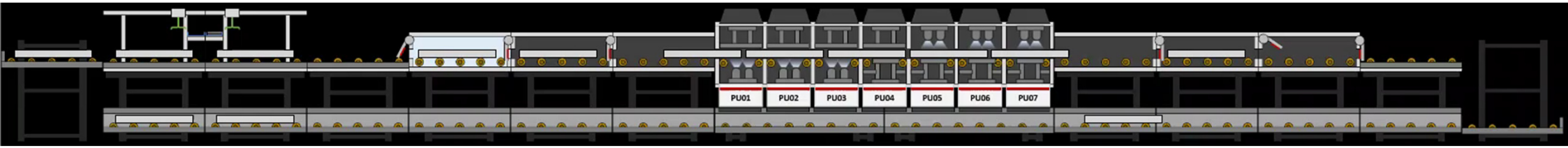
XEA|nova® L10

WET | PECVD | PVD | MET

HJT process flow



Entrance lock | Buffer | Transfer | Process chamber | Transfer | Buffer | Exit lock



- Horizontal inline carrier-based PVD Coater
- 100nm ITO front and rear site coating
- Multi-layer stack coating applicable

Virtual Reality Video Experience at
vonardenne.biz/en/xeanova-vr

VON ARDENNE KEY TECHNOLOGIES

Technology Competence Through Experience & Innovation

More than 45 years of know how in vacuum coating

Plasma Technology

Rotatable Dual Magnetron

Evaporation Technology

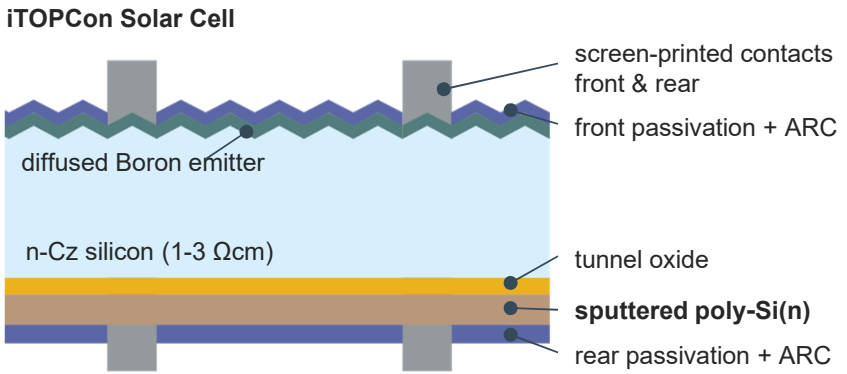
Linear Co-/Evaporation Unit

TOPCon	TO + aSi(n,p)	
HJT	TCO (e.g. ITO, AZO)	
IBC	TO + aSi(n,p), TCO, metals (e.g. Cu)	
Tandem	Rec. layer, ETL, HTL, TCO	Perovskites, ETL, HTL

PVD n:POLY FOR TOPCon

PROCESS SEQUENCE + ADVANTAGES

- Saw Damage Etching + Texturing
- BBr_3 Diffusion
- BSG-Etch + Emitter Removal (rear side) + Cleaning
- Tunnel Oxide (SiO_X) Deposition by PVD
- aSi(n) Deposition by PVD
- Annealing (poly-Si formation)
- Cleaning (HF-Dip)
- AlO_x / SiN_x (front side)
- SiN_x (rear side)
- Screen Printing + Firing
- Cell Sorting



- ☐ PVD is a reliable + scalable process for Mass Production
- ☐ Thickness and Sheet Resistance **homogeneity at ±3%**
- ☐ **no wrap-around** by PVD deposition process
- ☐ **no toxic gases** (e.g. PH3) required
- ☐ **no etch-back process needed**
- ☐ no yield-loss due to deposition + etch-back process
- ☐ no cost for PH_3 or SiH_4 facilities + safety requirements

PVD TECHNOLOGY FOR TOPCon

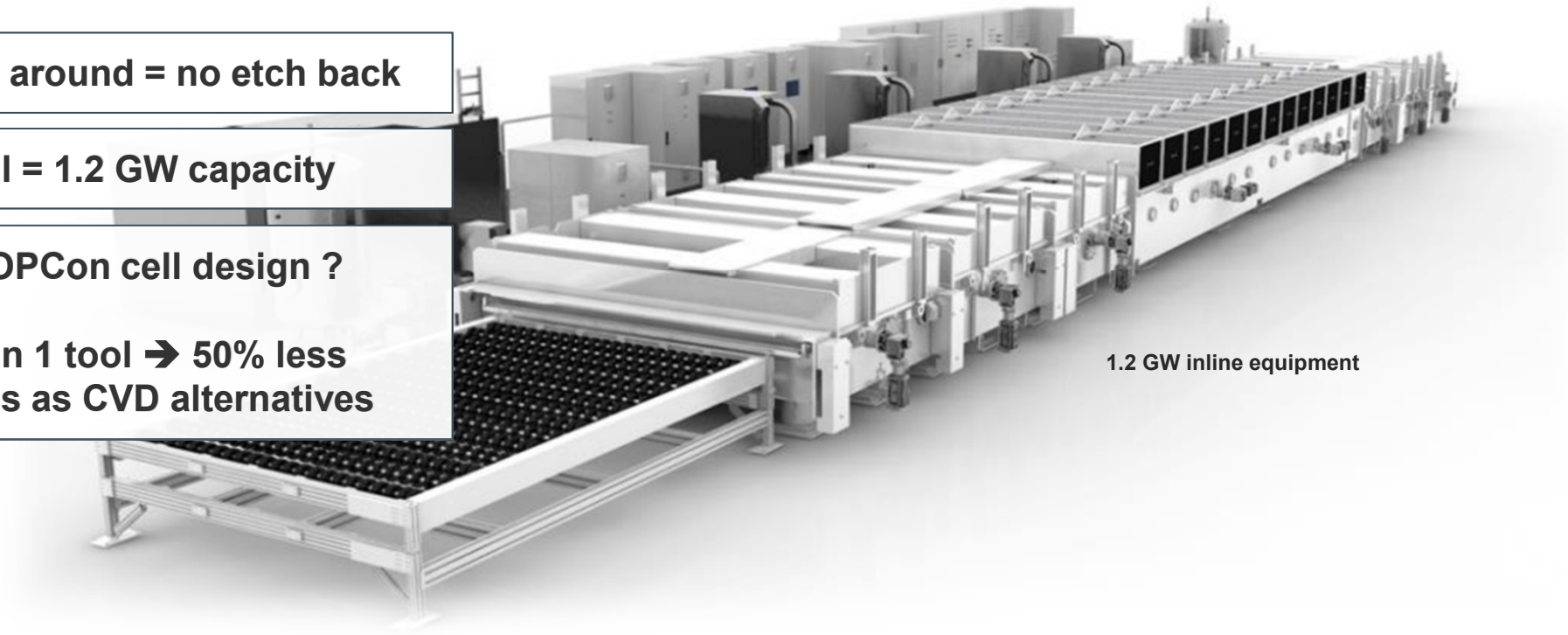
Why PVD-Technologies for TOPCon Manufacturing ?

1) No a-Si wrap around = no etch back

2) One PVD tool = 1.2 GW capacity

3) Two sided TOPCon cell design ?

   PVD does it in 1 tool ➔ 50% less TOPCon tools as CVD alternatives



1.2 GW inline equipment

PVD aSi(n) FOR TOPCon

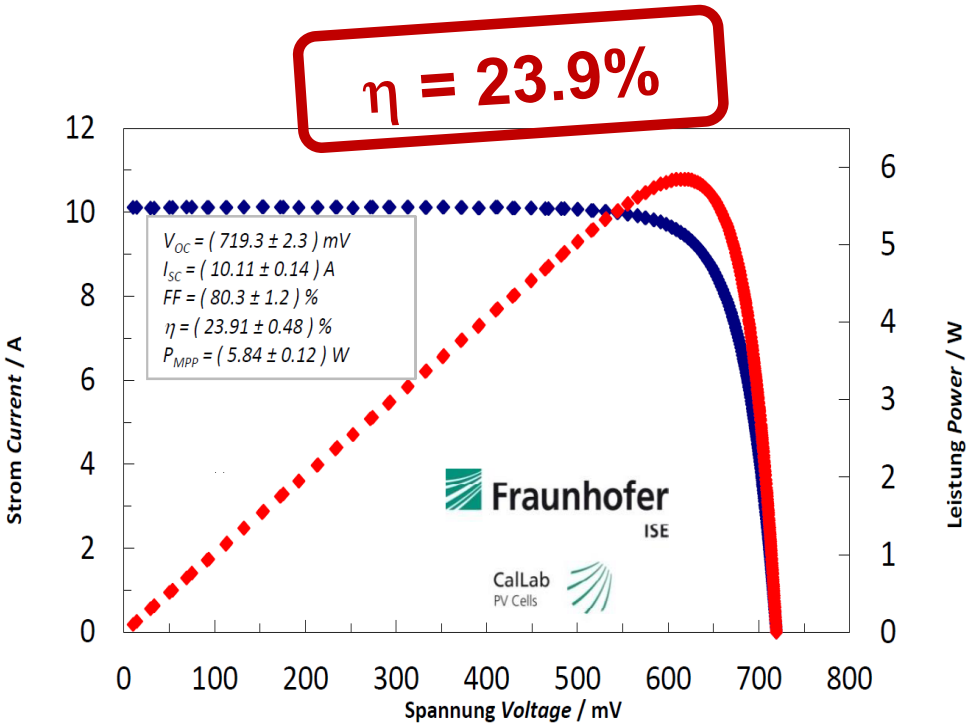
Key Takeaways

Developed with Fraunhofer ISE & ISC Konstanz

- ☐ i-TOPCon process sequence on n-Cz (M2)
- ☐ in-situ doped sputtered aSi(n) layer
- ☐ **Single-sided deposition !**
- ☐ Screen-print metallization for i-TOPCon

Cell Performance according to ISE CalLab PV Cells

- ☐ So far best PVD TOPCon cell **η = 23.9%**
- ☐ So far best PVD TOPCon cell **V_{OC} = 719mV**
- ☐ iV_{OC} of cell precursors shows potential of V_{OC} > 720mV
- ☐ Addressing FF-potential for further improvement
- ☐ **> 24.5% is work in progress by finetuning sputter process, anneal conditions and screen-printing**



Callibrated IV-measurement of i-TOPCon cell

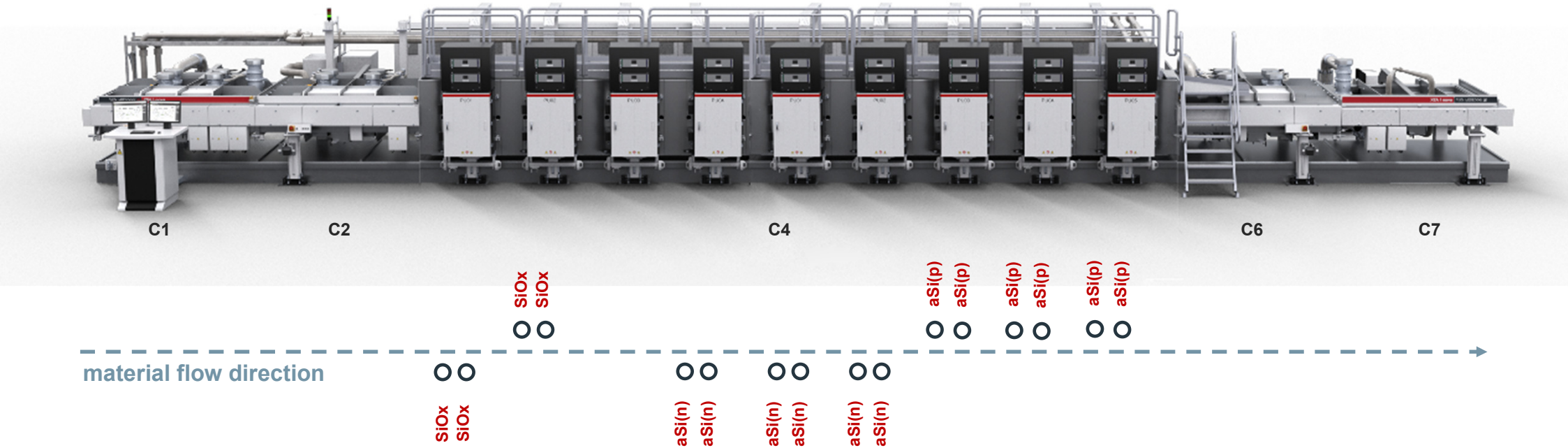
- 12 front busbars, no busbars on rear
- IV-measurement on golden chuck

VON ARDENNE – XEA|nova® L

In-line Sputter Equipment for Single- or Both- Sided SiO_X + aSi Deposition

Configuration Example for Tunnel Oxide + 100nm

- Horizontal inline carrier-based wafer coater
- No crane, easy, fast + safe maintenance
- Highest throughput in market for G/M12 format
- Dual-sided TOPCon deposition for future cell concepts possible in one equipment
- In-situ oxide tuneable to aSi(n) or aSi(p) as needed



LATEST EFFICIENCY RESULTS IN HJT PRODUCTION

Achieving 25% HJT with no sputtering damage process

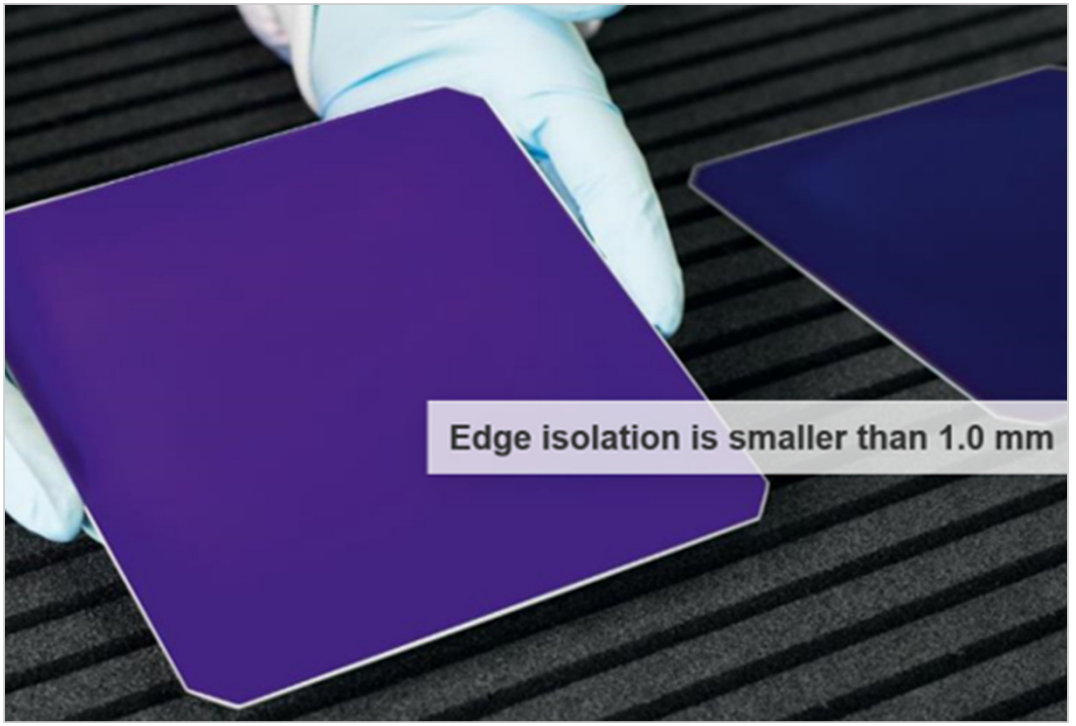
XEA|nova® production data

V_{oc} ≥ 750mV

η_{avg} ≥ 25.0%

η_{top} ≥ 25.3%

At different customer sites applying busbar technology



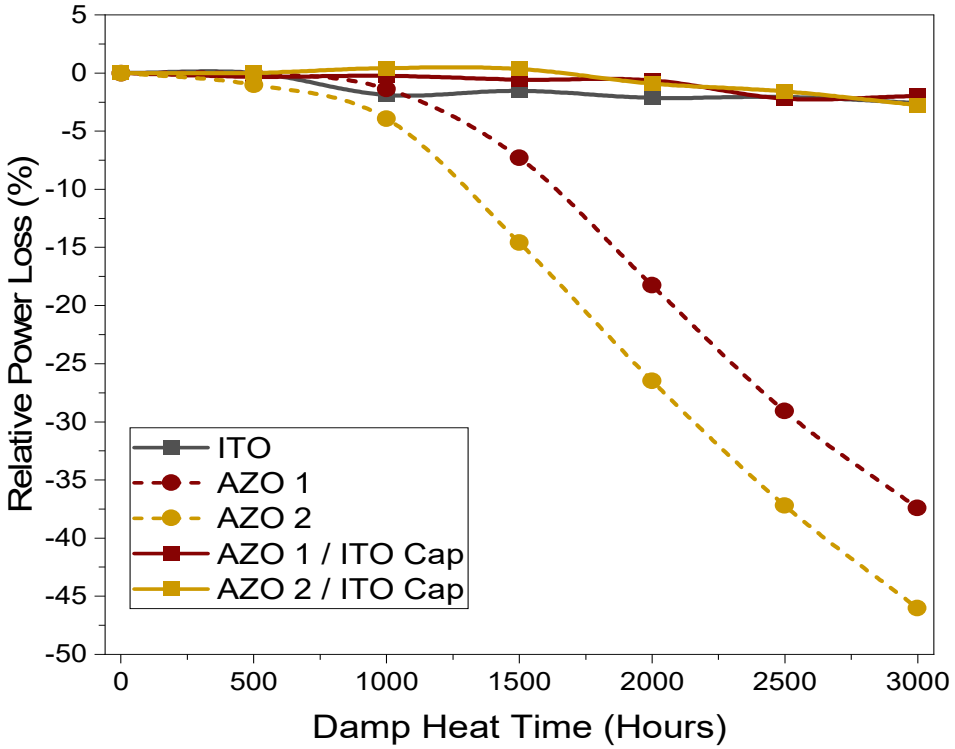
OPEX REDUCTION IN TCO COATINGS FOR HJT SOLAR CELLS

Stress testing of mini-modules with AZO/ITO

Module configuration and results from damp heat tests

- ☐ Median efficiencies of best ITO/AZO/ITO groups are both (front only & rear only) at level with the ITO reference
- ☐ **AZO / ITO stack is as stable as the single ITO layer in damp heat testing**
- ☐ Power loss after 3000h is less than 3%

- ➢ **ITO / AZO / ITO (20 / 70 / 20nm) leads to a 45% cost reduction** while saving 64% of ITO material
- ➢ Further cost reduction potential by decreasing the ITO thicknesses



Relative power loss of single cell modules due to six consecutive 500h of damp heat stress testing

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

SEED LAYERS FOR COPPER PLATING IN HJT OR IBC PRODUCTION

Next generation metalization to replace Ag Screen-Printing

Fully copper-coated HJT solar cell

- 60% CoO decrease potential compared to Screen-Printing*
- VA sputtering systems are deposited metal layers as seed layers for plating
- Strong adhesion for high-quality cell interconnection
- Approved at EU R&D institutes:
- GW production demonstrated

Fraunhofer ISE

csem

* T. Hatt et al., Low-cost Cu-plated metallization on TCOs for SHJ Solar Cells – Optimization of PVC Contacting-layer, IEEE 47th PVSC, DOI:10.1109/PVSC45281.2020.9300706

CHALLENGES TO BRING TANDEM SOLAR CELLS IN GW PRODUCTION

Scale up from ≤ 1cm² to wafer / module size

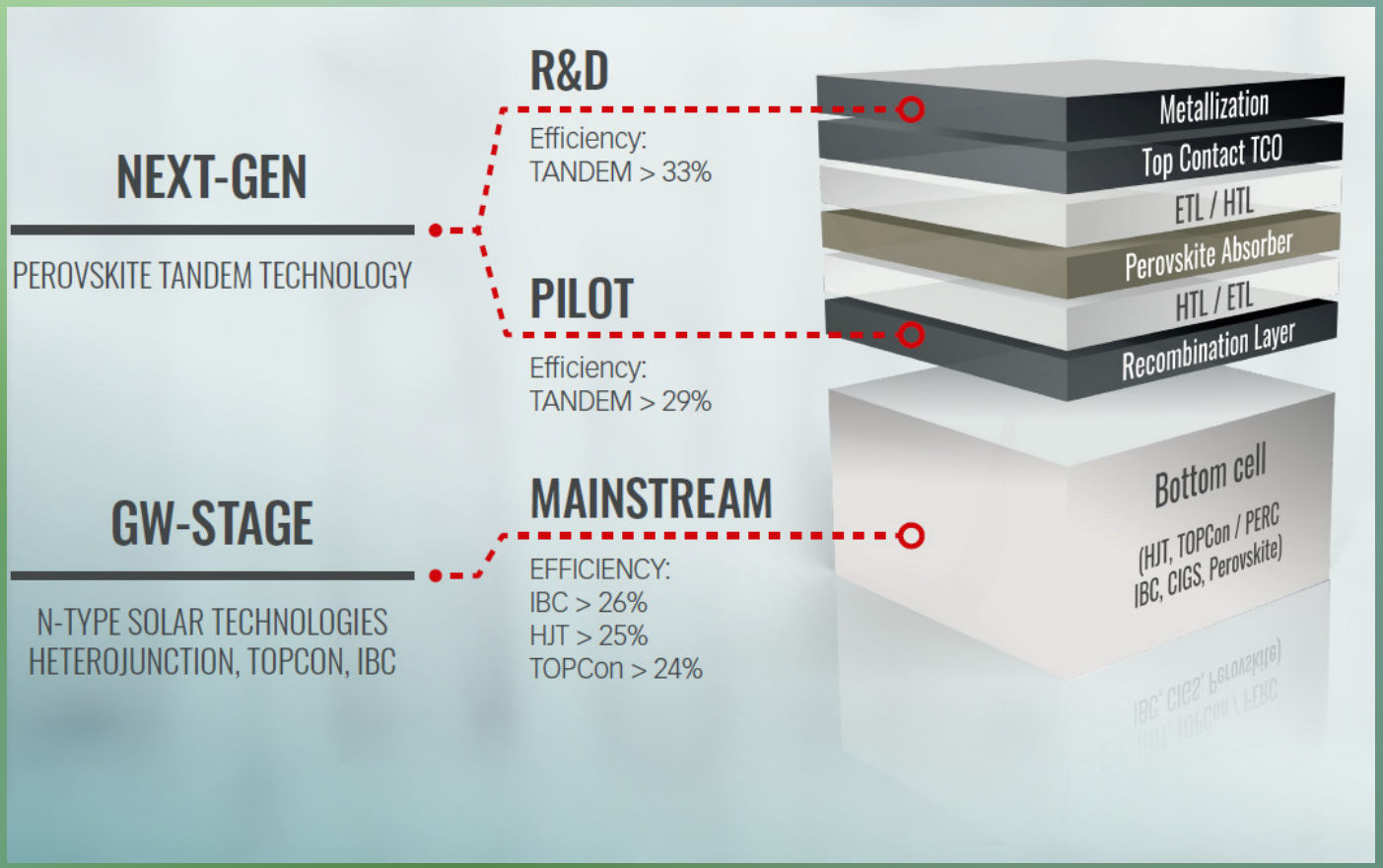
Implement process flow in pilot production

Improve the stability
(similar module stability compared to state-of-the-art PV)

Find a cost-effective process flow
(incl. chemical compositions, metallization, cell interconnection, encapsulation)

Vacuum processes or a combination with solution-based processes are considered as right technology approach to meet the challenges

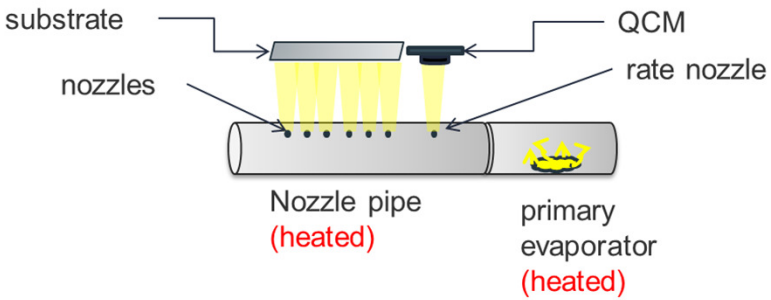
PVD DEPOSITION OFFERS FOR TANDEM TECHNOLOGY THE MOST STABLE AND REPRODUCIBLE PROCESS ENVIRONMENT



High Volume Manufacturing Requirements for Tandem

- Low damage or even damage free deposition
- High deposition rates
- Good layer and interface properties at low temperatures
- Stability over campaign time

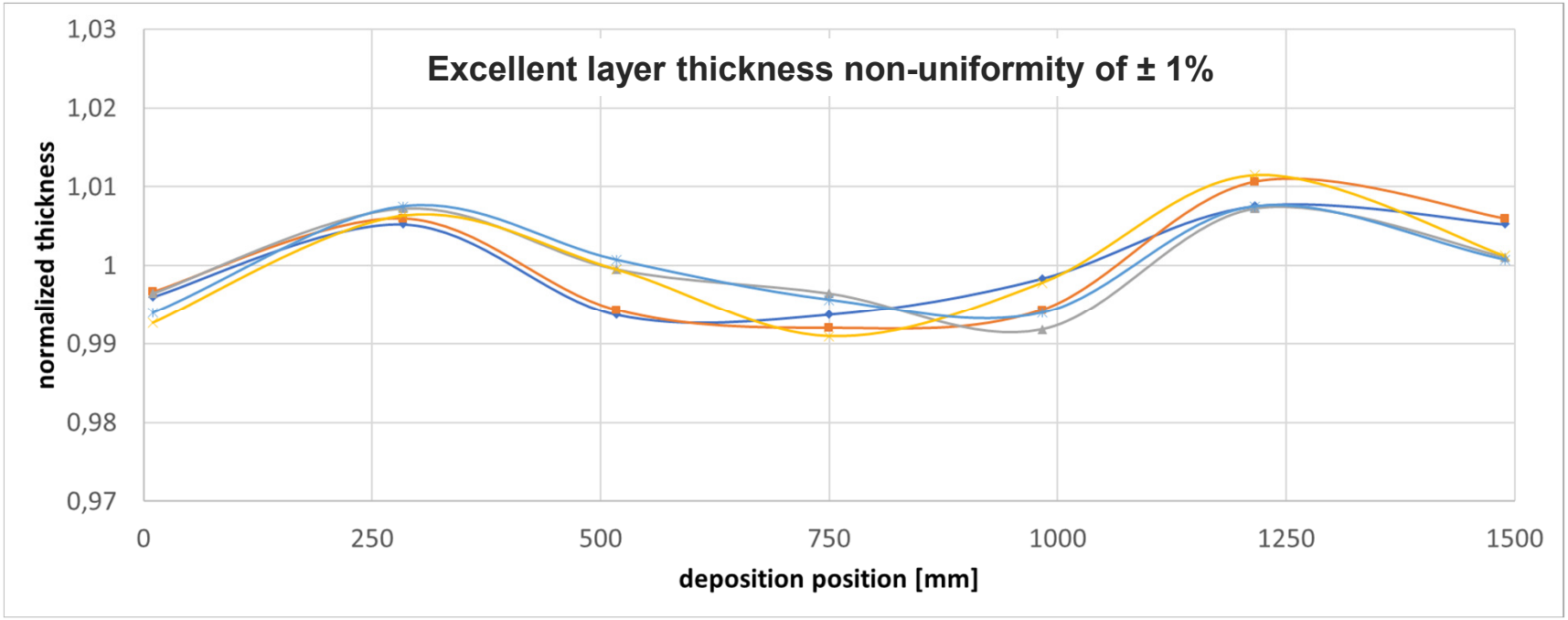
CO-EVAPORATION PROCESS UNIT



- Single-, Co-, up to 4fold-Evaporation with vapor up or down
- For organic and perovskite materials
- Industrial campaign times
- Integrated control system guarantees reproducibility and process stability

VON ARDENNE 1.5M LINEAR EVAPORATION SOURCE

PVD offers for Tandem Technology a stable and reproducible process environment



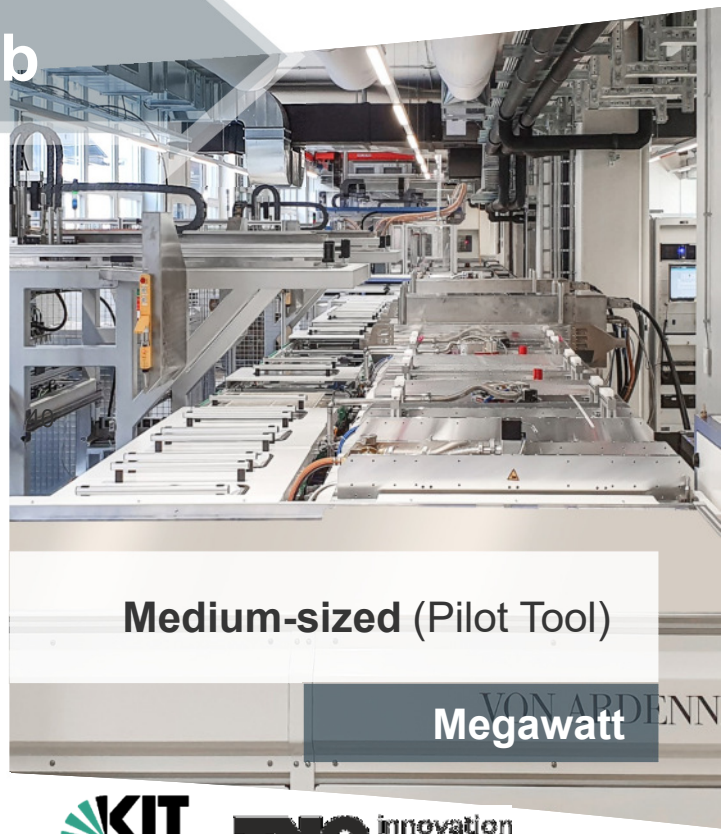
- ☐ Single, Co- or up to 4-fold evaporation
- ☐ Dynamic deposition rates: 0.4-300 nm*m/min
- ☐ Up to 750 °C possible
- ☐ Easy and fast refill of crucible

TANDEM & EMERGING PV IN EUROPEAN COLLABORATIONS

From Lab to Fab

Small (Lab Tool)

Watt



Medium-sized (Pilot Tool)

Megawatt

Large (Mass Production)

Gigawatt

SUMMARY

PVD as the Key Technology for GW Scale Photovoltaics

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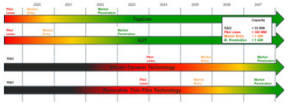
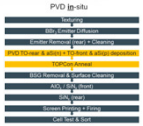
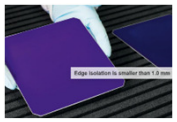


VON ARDENNE serves different areas in the field of technology and scaling

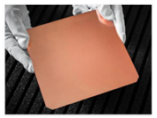
GW production: Horizontal inline carrier-based PVD Coater **200MW - 1300MW**



TOPCon PVD at same η level as LPCVD; huge cost saving potentials for both-sided TOPCon and IBC



HJT PVD resulting in $\eta_{avg} \geq 25.0\%$, $\eta_{top} \geq 25.3\%$ busbar technology



Copper plating for HJT and IBC**: PVD metal layers as seed layers**

Tandem: Available PVD capabilities for scaling up towards MW and GW

WE ARE HIRING

Become part of a modern family business and shape the future with us.

- international technology company
- more than 1000 employees in 6 countries
- more than 60 years of experience in vacuum technology
- for solving the energy problems of the world

For more information

https://www.vonardenne.biz/en/careers/vacancies