NICE SOLAR ENERGY

Progress in development of CIGS processes and modules at NICE Solar: status and future outlook

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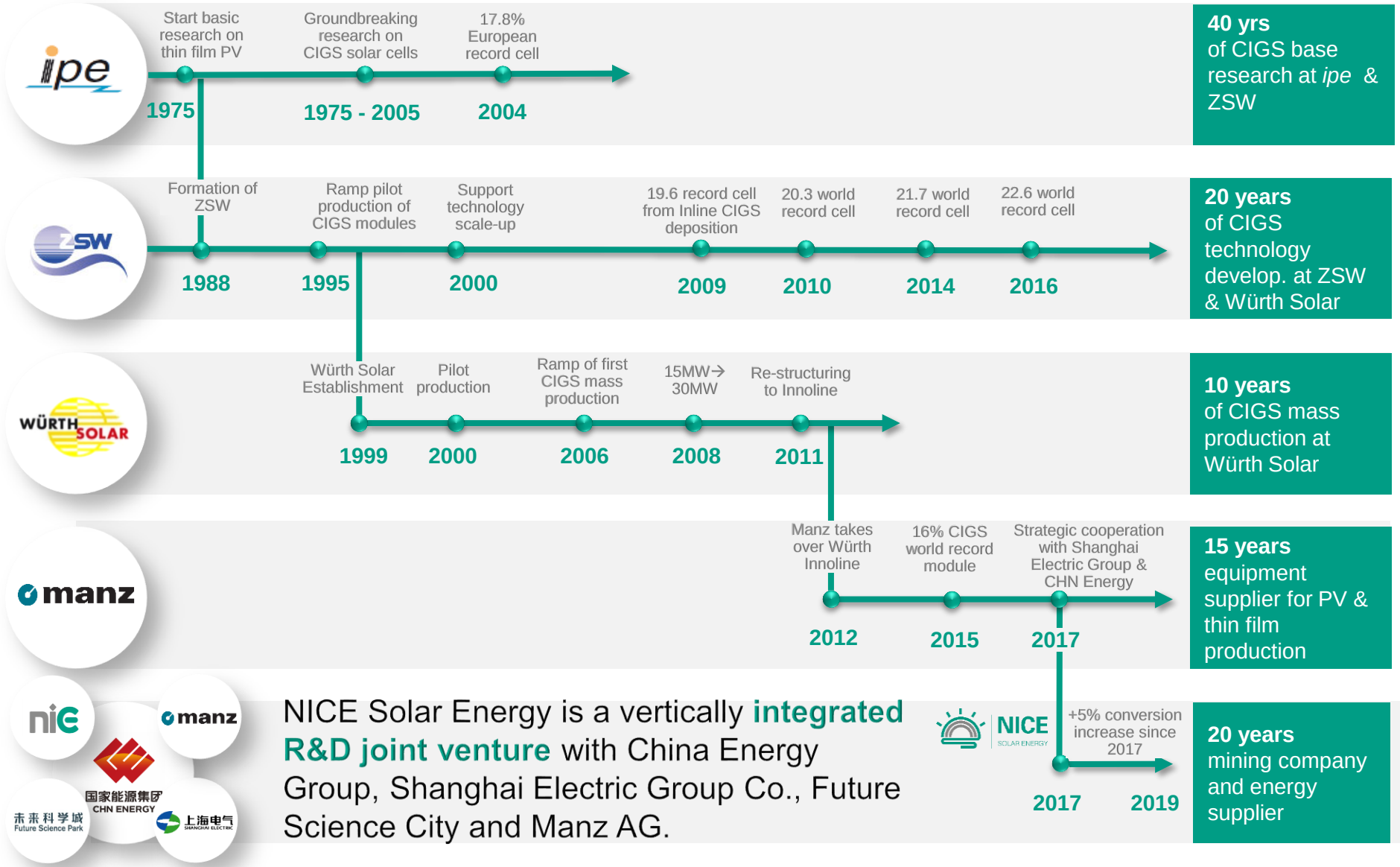
Outline

- NICE Solar Energy
- Technology Status
- Efficiency Analysis
- Technology Developments
- Summary & Outlook


NICE Solar Energy

Development of CIGS processes and modules at NICE Solar
Our Roots



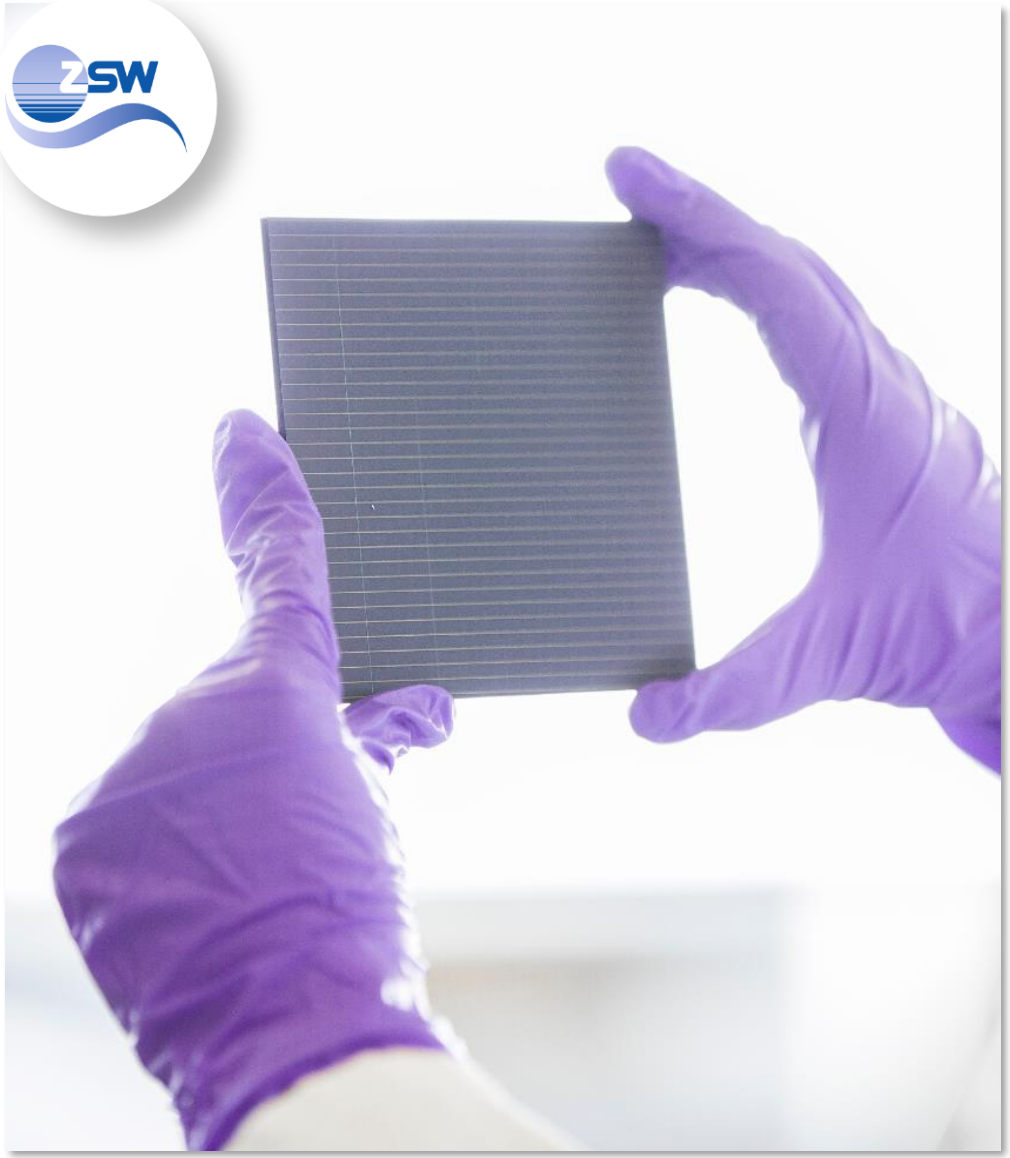
Development of CIGS processes and modules at NICE Solar
Ramp-up of CIGSfabs in China

306 MW Customer: Chongqing Shenhua thin film solar technology co., Ltd.
~ 106 Equipment/processes (14 CIGS Coater, ~ 8000 solar panels/day)

44 MW Customer: Nice Solar Energy Ltd.
~ 32 Equipment/processes (2 CIGS Coater, ~ 1100 solar panels/day)


Technology Status

Our Partners | ZSW



ZSW: Center for Solar Energy and Hydrogen Research Baden-Württemberg

→ Our exclusive development partner in the field of CIGS thin-film photovoltaics

ZSW's researchers currently hold a cell efficiency of 22.6% for CIGS solar cells.

Development of CIGS processes and modules at NICE Solar
World Efficiency Record on Total Area with 17.6% (December 2019)


Efficiency Analysis

Development of CIGS processes and modules at NICE Solar
What makes the Efficiency gap?

record cell
efficiency benchmark

Efficiency gap of 8%

Record Cells and Production Modules are different

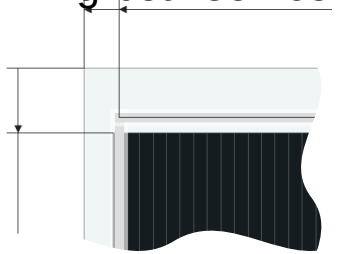
- What are the loss mechanisms?
- How much efficiency can be transferred from record cell to production module?

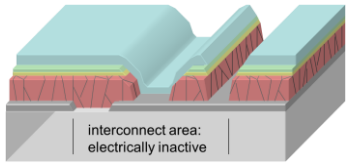
production module average efficiency

Loss analysis of CIGS cells without/with metal grid

Geometric losses (module design)

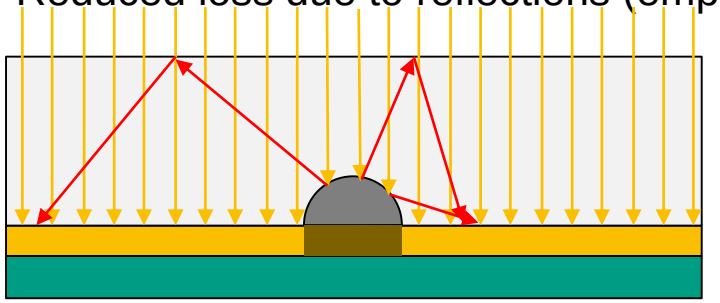
- Edge ablation, contact area
- Monolithic patterning between cells





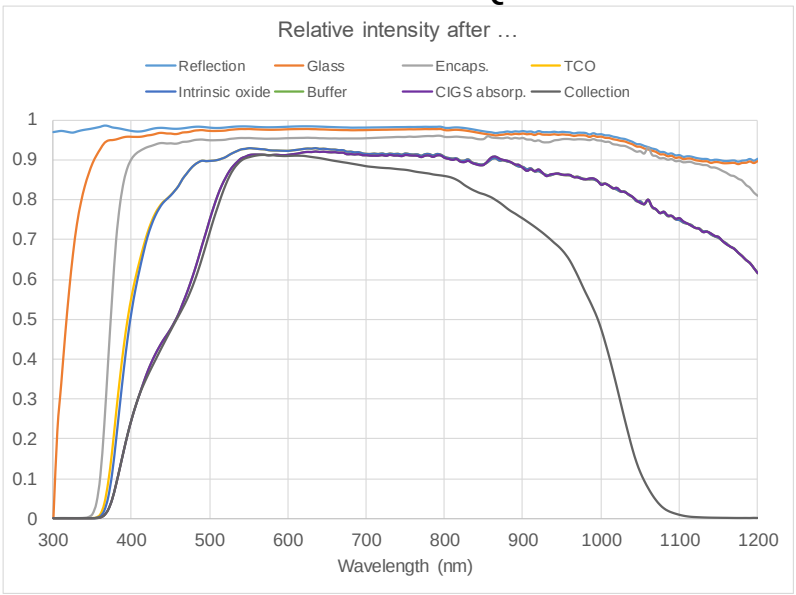
Metal Grid shadowing

- Reduced loss due to reflections (empirical)



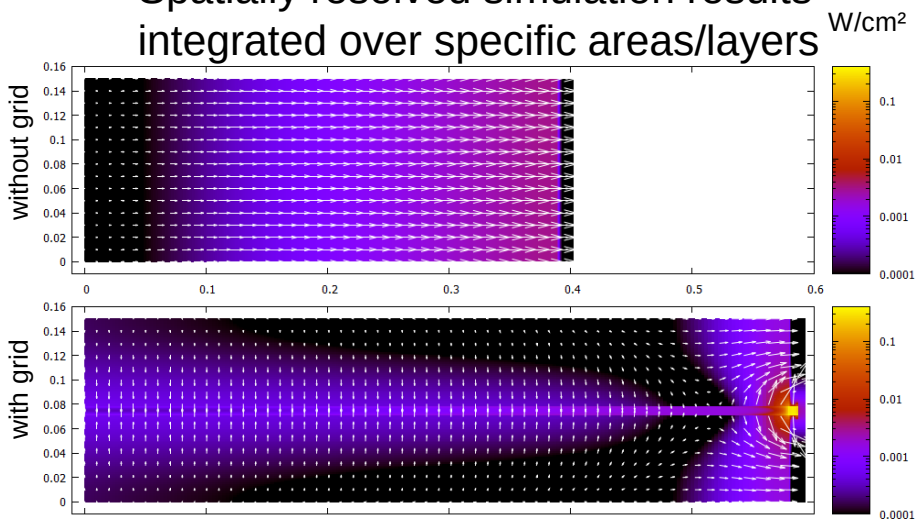
Optical losses (layer stack)

- Approximate calculation from T/R and QE



Electric losses

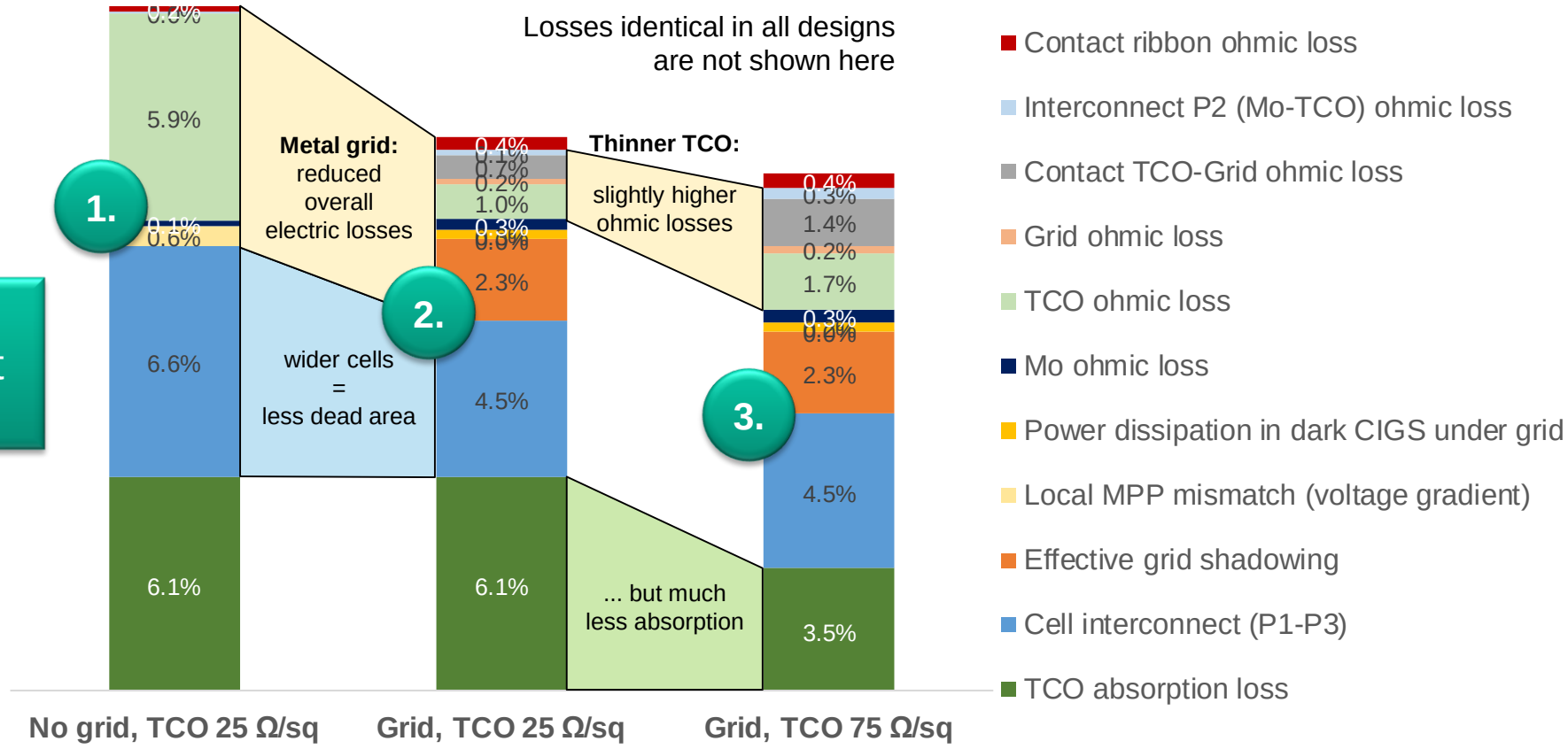
- Cell simulation with PVMOS
- Spatially resolved simulation results integrated over specific areas/layers



Simulated TCO current (arrows) and dissipated power (color) cell map

Loss analysis of CIGS cells without/with metal grid

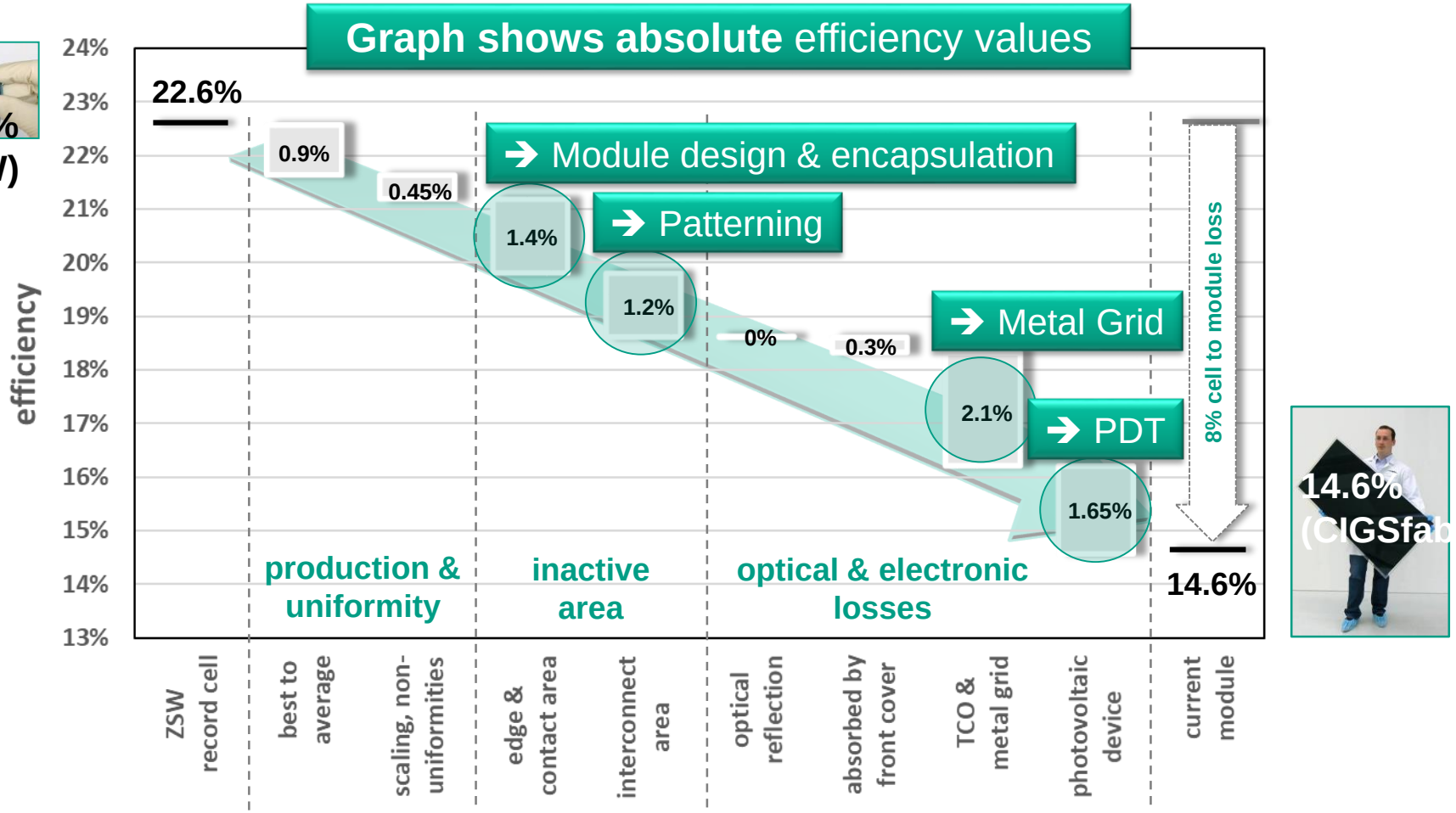
Relative loss values against ideal case:



1. Module without grid: main losses are **TCO ohmic loss**, **interconnect area** and **TCO absorption**
2. **+ metal grid + wider cells: reduced TCO ohmic loss and interconnect loss**, minor additional grid losses
3. **+ thinner TCO: strongly reduced absorption loss**, slightly higher ohmic losses

➔ **Total gain approx. 6%**, confirmed experimentally on large-area modules

Development of CIGS processes and modules at NICE Solar
Efficiency Gap Analysis: Record Cell to Module losses



➔ Loss analysis allows to assign, prioritize & setup appropriate efficiency projects
➔ Identify & separate non-addressable losses before (e.g. electrical insulation)


Technology Developments

Development of CIGS processes and modules at NICE Solar
Focus items in R&D for next-generation CIGS modules

CIGS Device Enhancement

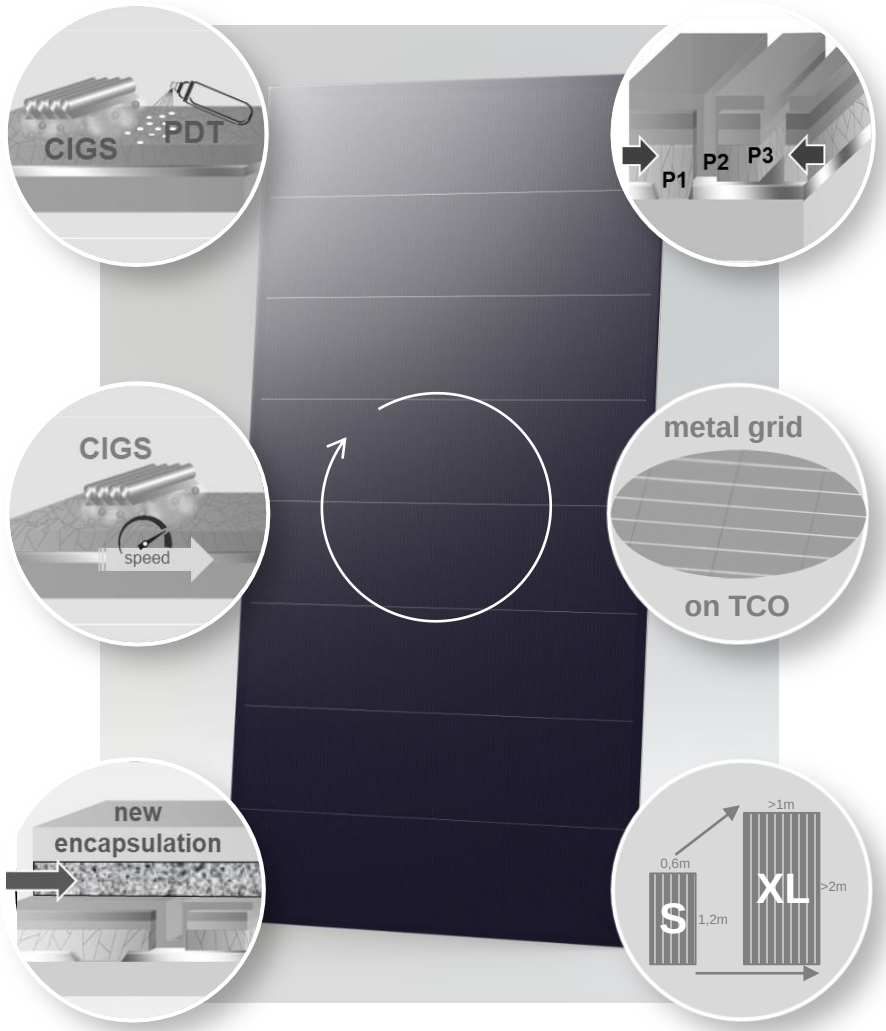
by post-deposition treatment (**PDT**) of CIGS layers with alkali metals for **increased device efficiency**

High speed CIGS coating

for lowest CAPEX and **reducing production cost**

New encapsulation

using polyolefin materials and **cemented-joint** structures for low cost and long-term stability
➔ **less edge area losses**



Improved interconnects

dead-area widths down to 150 µm utilizing novel interconnect schemes and active line tracking

Metal Grid Structures

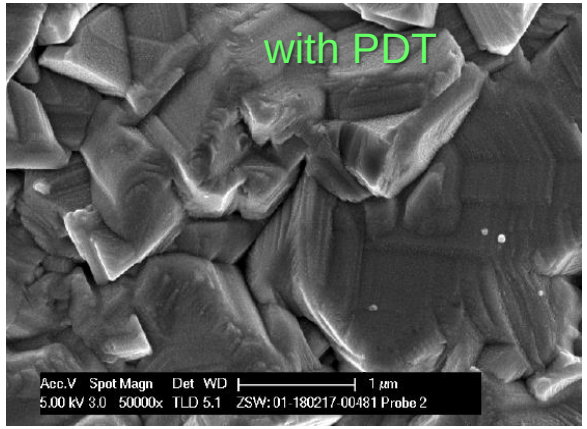
improved charge carrier collection at the **front contact** and **reduced module voltage**

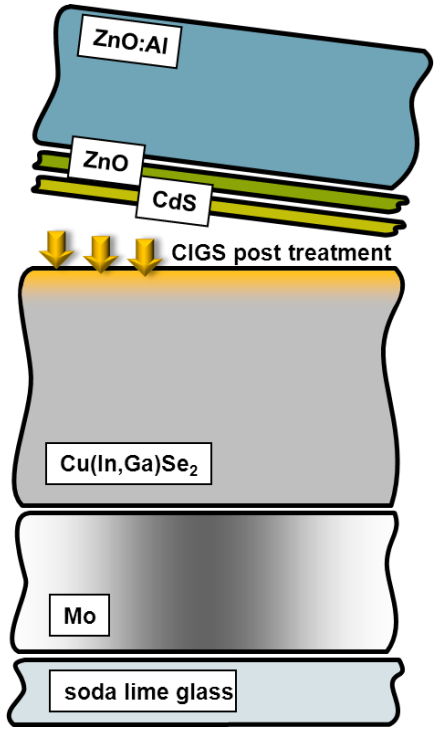
Module Size >2m²

utilizing the advantages of thin-film deposition technology and **substantially reducing module cost**

Development of CIGS processes and modules at NICE Solar
Effects of PDT on the layer structure

- **RbF** used as **alkali source**
- **Coverage of CIGS surface with CdS is better** ➔ thinner CdS buffer layer (50nm ➔ 20nm)
  - → increase of $\mathbf{J_{SC}}$
- **Passivation of grain boundaries** leads to reduced recombination of charge carriers
  - → increase in $\mathbf{V_{OC}}$
  - → increase in **FF**

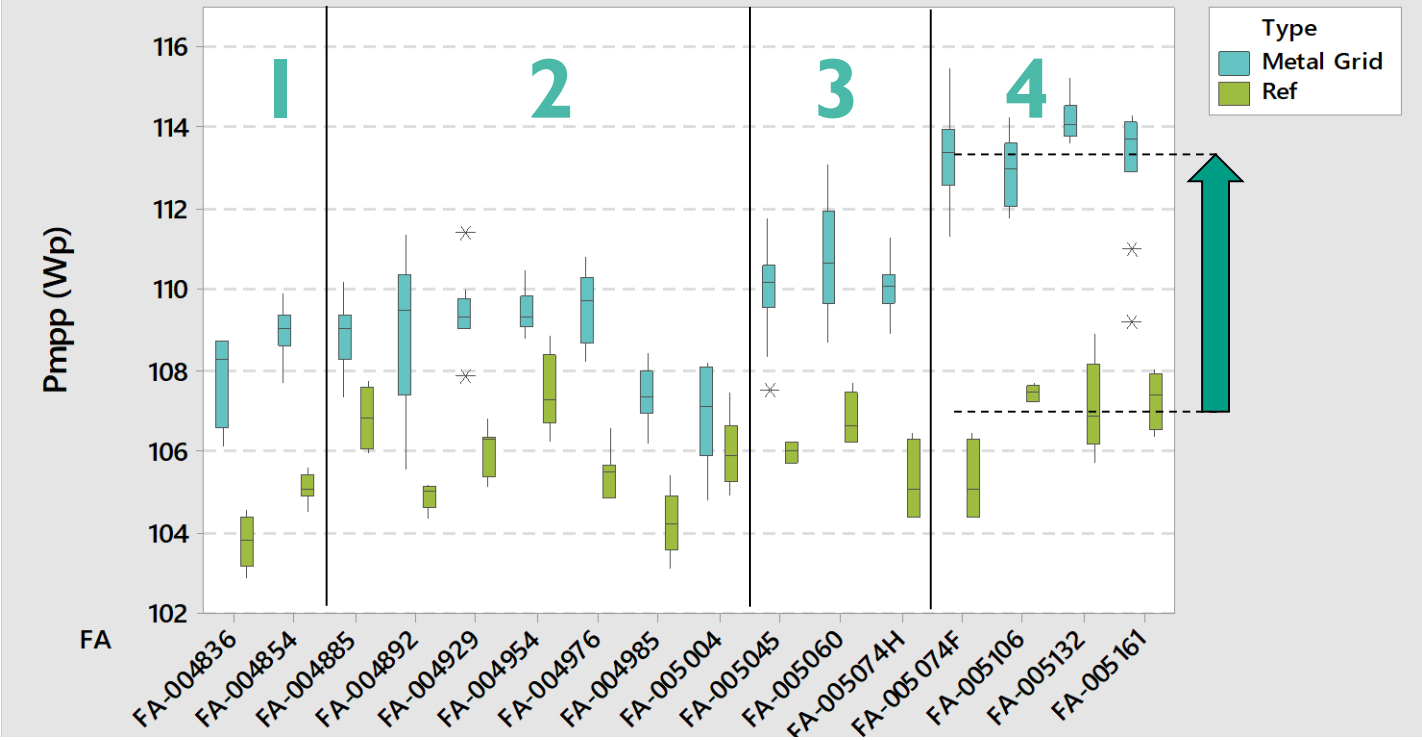




➔ +4 Wp gain through PDT realized

Metal Grid through Screen printing

- Comparison of reference and metal grid module production runs:



Development steps:

1. First process 1.0
2. Optimization of ITO/ZnO TCO stack
3. Optimization of cell width, finger pitch and TCO thickness
4. Improved screen-printing set-up

➔ +6..7 Wp gain through metal grid

Development of CIGS processes and modules at NICE Solar
Module generations

1.

- CIGSfab start

- **Panel size 0.72 m²**
- **Efficiency 14.6 %**
- **System voltage 1000 V**
- **Module voltage 100 V**

2.

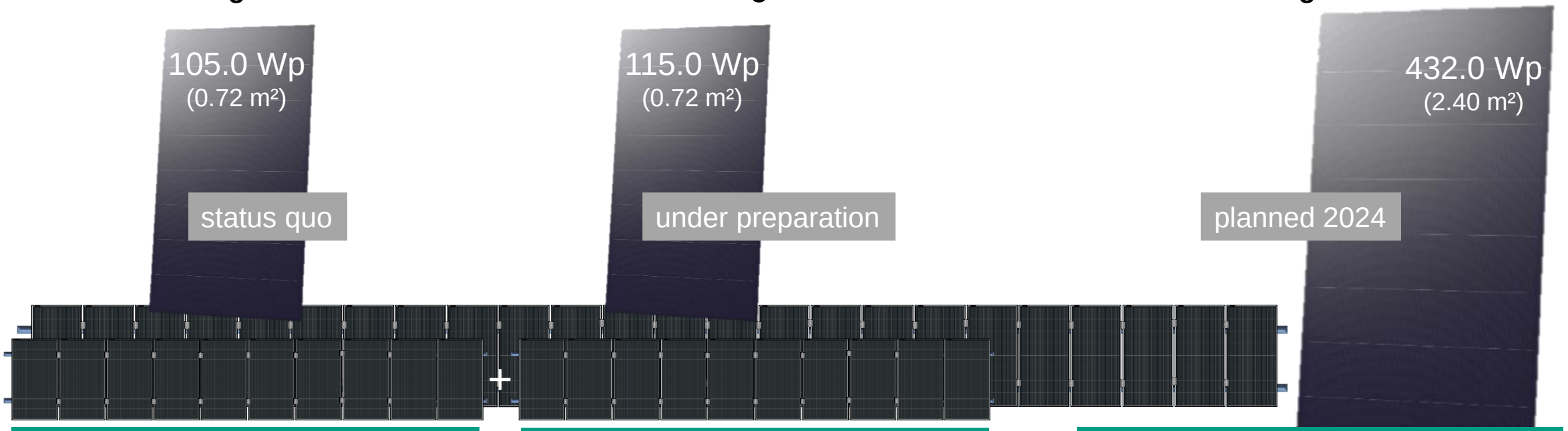
- metal grid
- PDT
- CJ & 1500V
- less dead area

- **Panel size 0.72 m²**
- **Efficiency 16-17 %**
- **System voltage 1500 V**
- **Module voltage 70 V**

3.

- XL size
- new coating technology

- **Panel size 2.4 m²**
- **Efficiency 18.0 %**
- **System voltage 1500 V**
- **Module voltage 55 V**



➔ ≈1 kW_p string (10 modules)

➔ ≈2.3 kW_p string (20 modules)

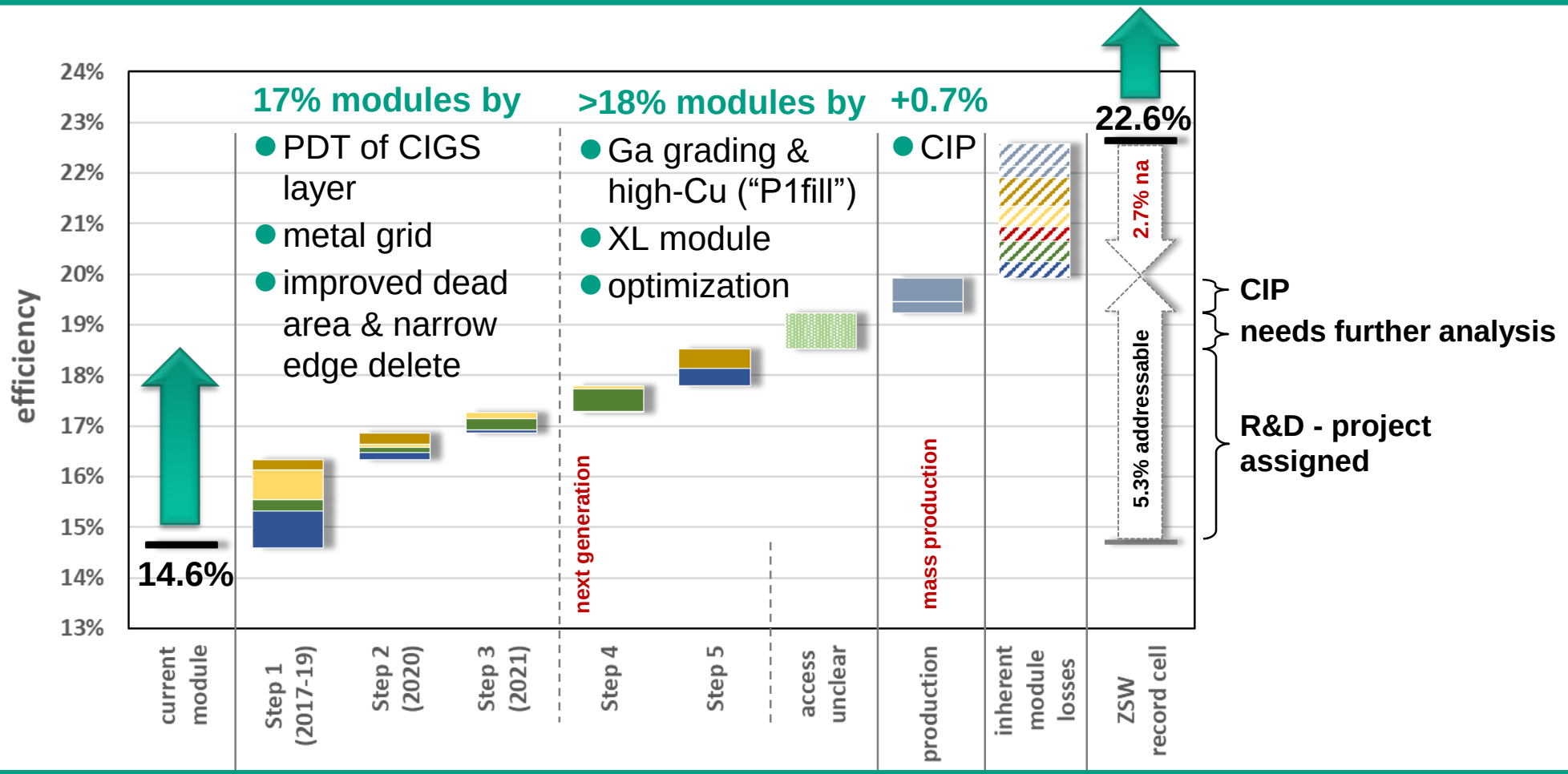
➔ ≈10 kW_p string (24 modules)

Summary & Outlook

Development of CIGS processes and modules at NICE Solar
Summary

- Two CIGSfabs in China are prepared for start-up and process implementation
- Technical breakthroughs in projects PDT, metal grid and improvements in dead area ➔
  - → record module efficiency of 17.6%
- Efficiency gap of 8% between ZSW record cell and current CIGSfab module technology
- Efficiency potentials are addressed through R&D projects. These are developed and planned as upgrades for CIGSfabs:
  - → new encapsulation ➔ allows module design with narrow edge through cemented joint
  - → metal grid ➔ reduces front contact losses
  - → PDT ➔ reduces buffer losses and improves passivation
  - → improved patterning ➔ reduces dead area losses

Development of CIGS processes and modules at NICE Solar
Module Efficiency Roadmap



➔ 17% production type modules are potentially possible in 2021, +0.7% by CIP in production
➔ 18% with next-generation technology: XL module size, new CIGS source technology
➔ future developments require increase in efficiency at both ends, on **cell level and module level**

Outlook

Cell efficiency

- Reduction of device losses mainly in infrared
- Tandem cell concepts

Industrial processes

- CIGS absorber composition and gradients
- Improved equipment utilization and low energy consumption
- Large-area CIGS coating

Module efficiency

- Large-area modules
- New interconnect techniques

THANK YOU VERY MUCH FOR YOUR ATTENTION!

Acknowledgements:

- PVMOS simulation software:
  - → B. Pieters, “A free and open source finite-difference simulation tool for solar modules”, 2014 IEEE 40th Photovoltaic Specialist Conference, PVSC 2014, 1370-1375. DOI: 10.1109/PVSC.2014.6925173
- Funded by *Bundesministerium für Wirtschaft und Energie* within 6th framework of energy research program, project TAPAS under 0324234B

- Contributions from the team of NICE SOLAR ENERGY

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