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Filling in the gaps: The evolution of high-density module design

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FILLING IN THE GAPS:
THE EVOLUTION OF HIGH-DENSITY MODULE DESIGN

TECHNICAL POSSIBILITIES AND CHALLENGES

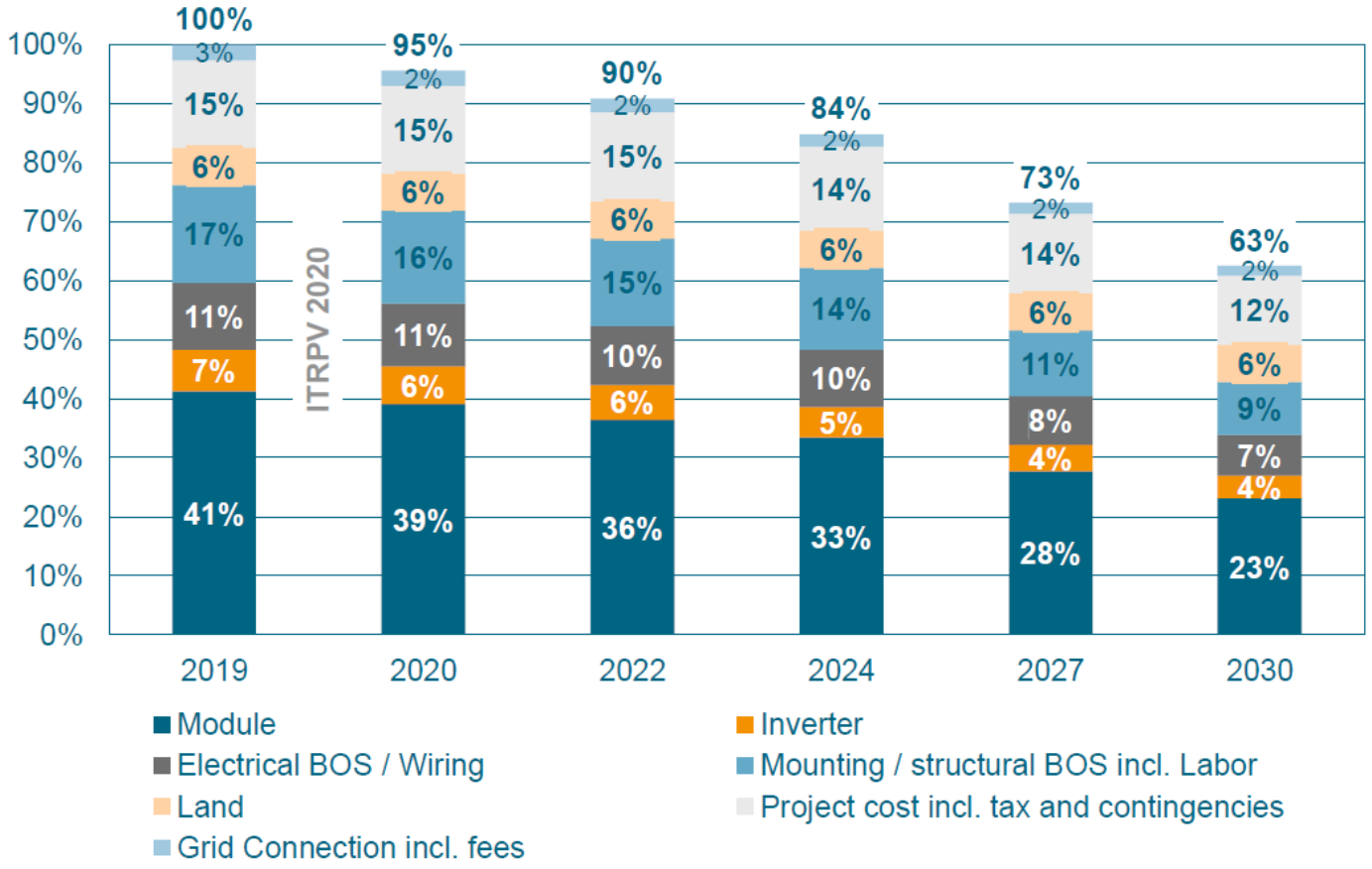
DR. BENGT JÄCKEL

OVERVIEW

- Motivation
- What does „high density“ mean?
- What concepts exist to reach higher power densities?
- Comparison discussed concepts
- Conclusions

MOTIVATION

CAPEX COST REDUCTION POTENTIAL



ITRPV 2020

- Land cost – constant
- Mounting – almost constant

➔ **more efficient modules** can reduce installation costs

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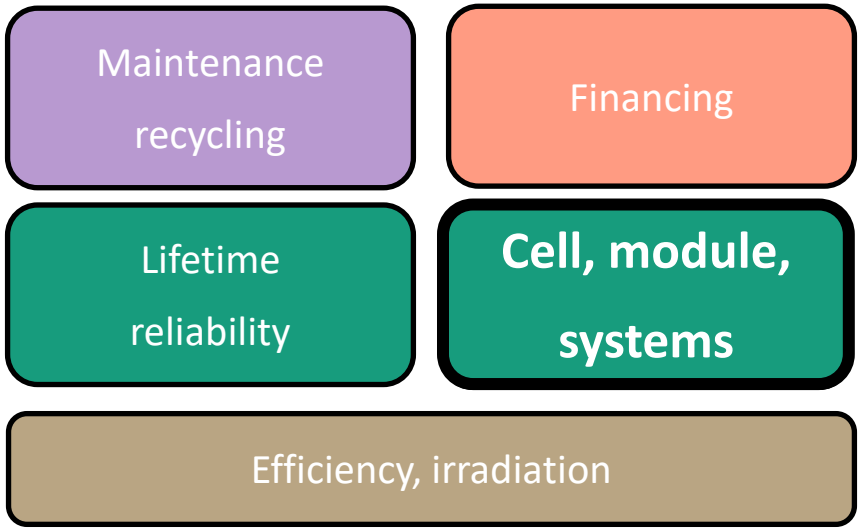
MOTIVATION

COST REDUCTION POTENTIAL

$$LCOE_{PV} = \frac{I_{PV} + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t} + R_n}{\sum_{t=1}^{n} \frac{M_{el} \times (1-d_{PV})^t}{(1+i)^t}}$$



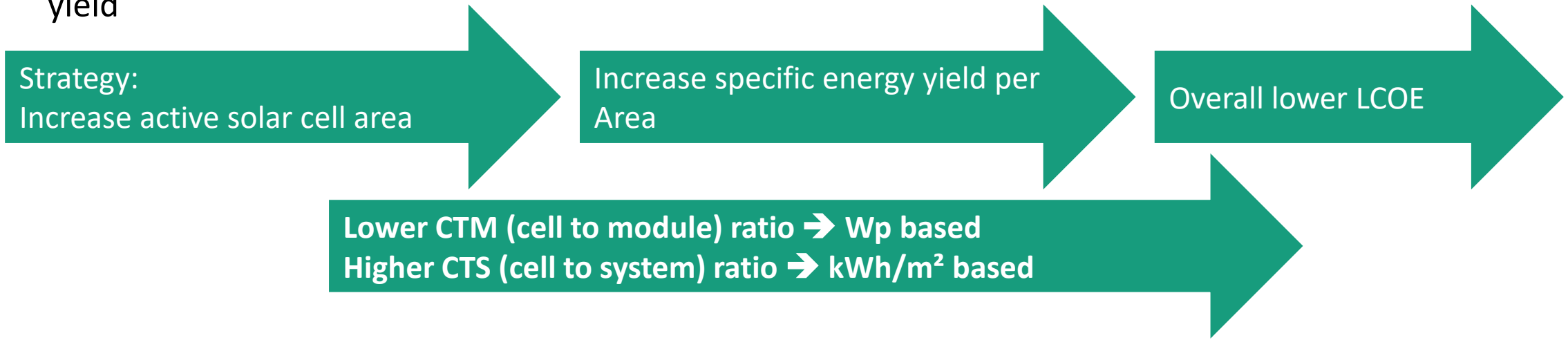
I_{PV}: Investment costs
A_t: Annual total costs
R_n: Removal costs
n: Lifetime in years
M_{el}: Electricity output
d_{PV}: Degradation rate
i: Discount rate
t: Operating year

THE PATH TOWARDS HIGH DENSITY PV MODULES

WHAT DOES HIGH DENSITY MEAN?

- PV industry is used to Watt-Peak!
- PV manufacturing industry is „paid“ in Watt-Peak!
- BUT: Owners and investors are „paid“ in kWh or kWh/m²

- High Density for PV modules: Highest possible Watt-Peak per Area that leads to the highest energy yield



THE PATH TOWARDS HIGH DENSITY PV MODULES

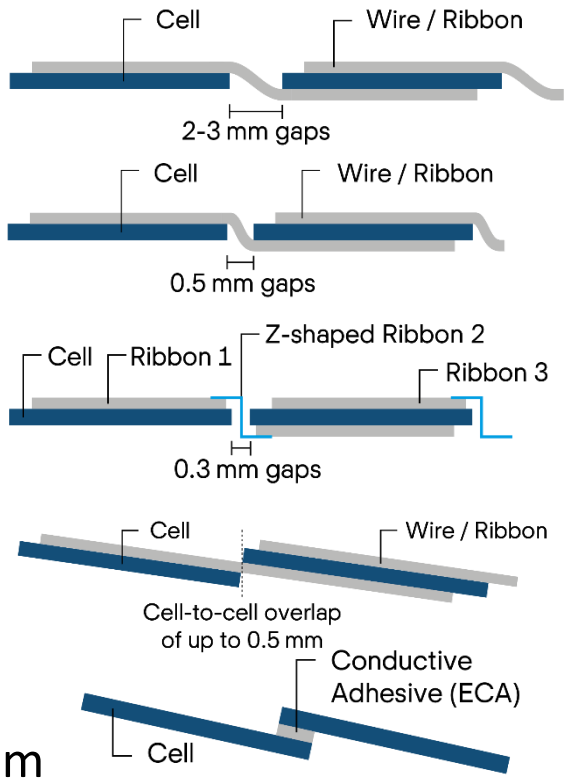
INCREASE SOLAR CELL EFFICIENCY AND ACTIVE AREA

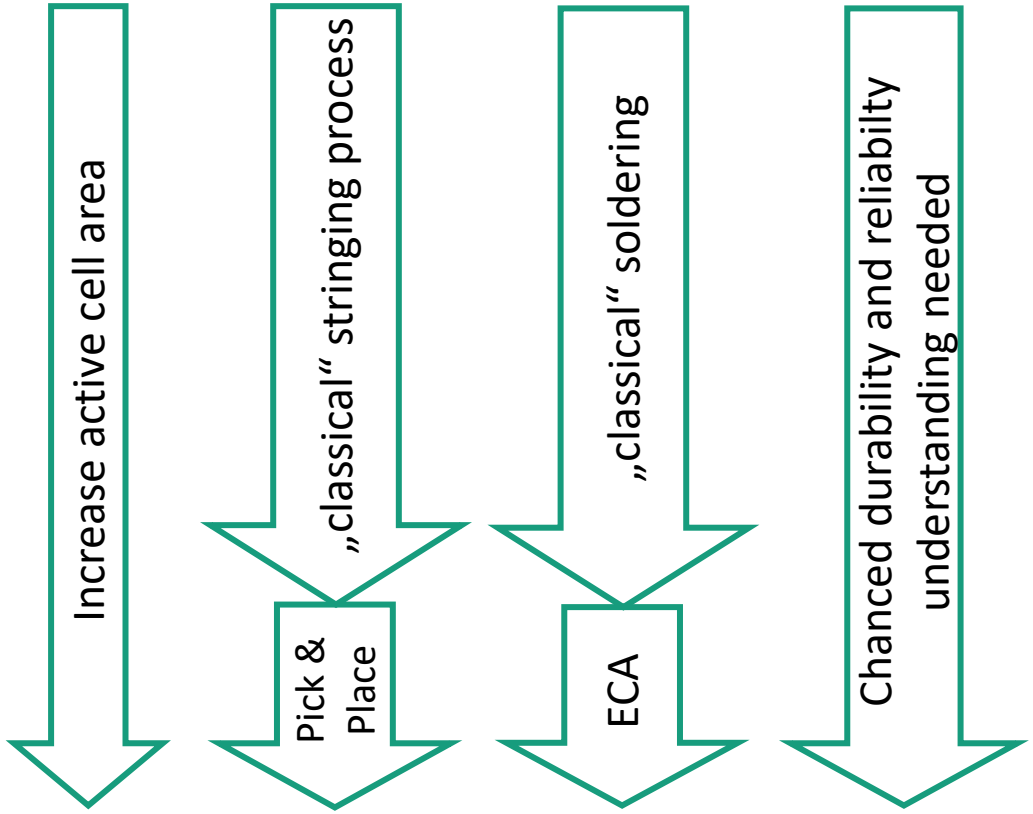
- **Increase solar cell efficiency:**
  - Today typically Mono-Material, move to n-type Silicon
  - Reduced optical and ohmic losses due to multi-busbar/wire interconnections (module)
  - Back-contact cells or heterojunctions solar cells, bifacial
- **Increase PV module efficiency**
  - Optimize cell spacings and optical coupling of materials to gather as much light as possible
  - Cut cells – typically “half-cut” –potential trend to “third-cut”
  - Use e.g. of highly reflective back-sheets, UV transparent encapsulants, light capturing ribbons
  - Add power boost by utilizing Bi-facial solar cells and appropriate transparent back-sheets

THE PATH TOWARDS HIGH DENSITY PV MODULES

INCREASE SOLAR CELL EFFICIENCY AND ACTIVE AREA

- **Increase PV module efficiency ➔** Optimize cell spacings
  - Standard
    - 2 - 5mm spacing
  - Small Gaps
    - 2 - 0.5mm spacing
  - Paving
    - Extra ribbon
  - Zero Gap
    - Overlap: 0.2 – 0.5mm
  - Shingled cells
    - Overlap: 0.5 – 1.0mm





THE PATH TOWARDS HIGH DENSITY PV MODULES

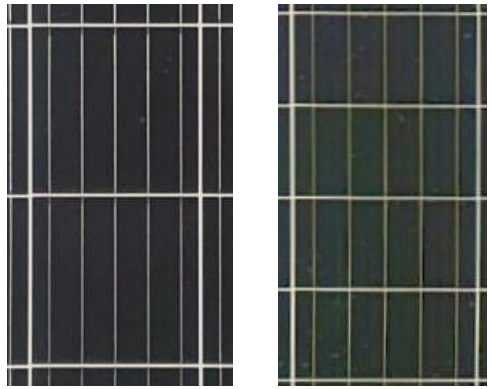
CHALLENGES

- Standard: Well understood – developed since industry beginning
- Small Gaps and Paving
  - More advance stringing process – multi-ribbons needed
  - Increased risk of cell breakage due to cell interconnects → Lamination process
- Zero Gap
  - “almost” standard stringing process
  - Optimized lamination process needed
- Shingled cells
  - Multi-cut cells – typically 1/5 or 1/6
  - Pick & Place process
  - ECA used as cell interconnection material (ECA application by dispenser or screen printing process)

THE PATH TOWARDS HIGH DENSITY PV MODULES

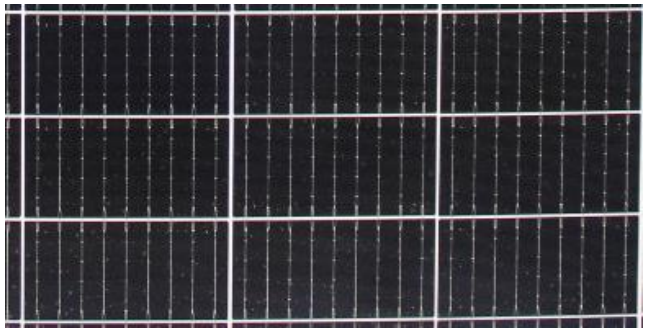
OPTICAL APPEARANCE

- Standard

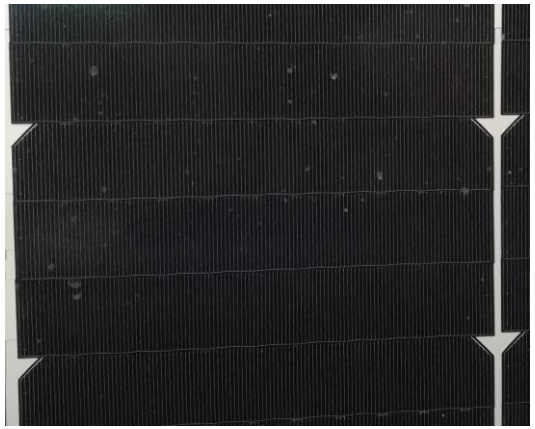


- Zero-Gap

- Smaller Gaps, Multi-Busbar



- Shingled cells



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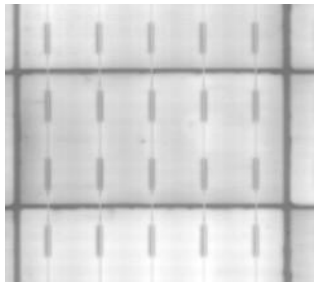
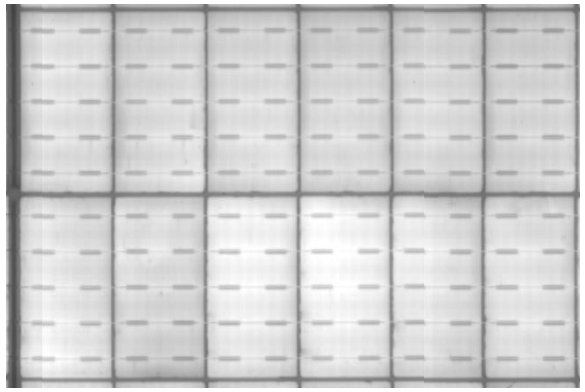
THE PATH TOWARDS HIGH DENSITY PV MODULES

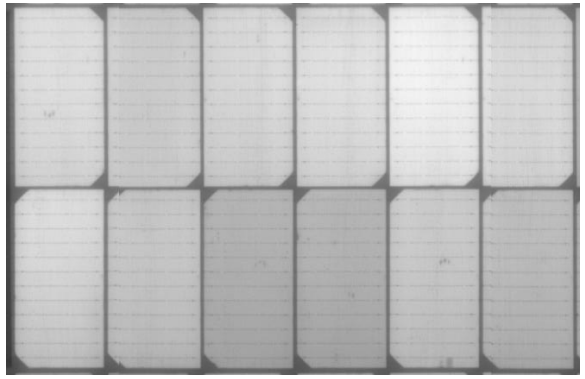
ELECTRO-LUMINESCENCE

- Standard

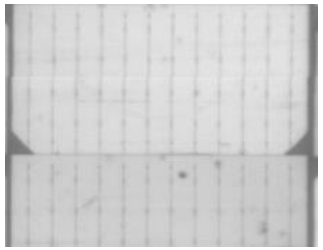


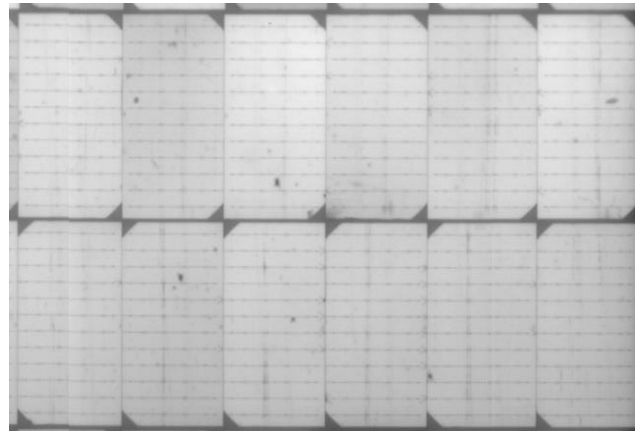


- Smaller Gaps, Multi-Busbar

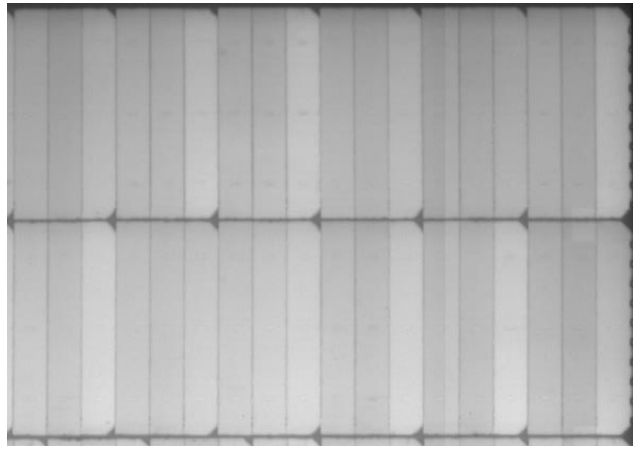


- Zero-Gap





- Shingled cells



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THE PATH TOWARDS HIGH DENSITY PV MODULES

MARKET: W_P FOR DIFFERENT DESIGNS/COLORS

- Standard
  - white ~400Wp
  - black ~ 325Wp
- Small Gaps and Paving
  - ~450Wp
- Zero-Gap
  - Qcells XL white ~460Wp
  - Qcells white ~390Wp
  - Q-cells black ~385Wp
  - others white ~460Wp
  - Others black ~ 380Wp
- Shingled cells
  - white~410Wp
- Larger Cell modules → Cut 210mm cells
  - white 500Wp

THE PATH TOWARDS HIGH DENSITY PV MODULES

MARKET: W_P → W_P/m^2

- Standard
  - white ~400Wp – Size ~ 2.01m²
  - black ~ 325Wp – Size ~ 1.70m²
- Small Gaps and Paving
  - ~450Wp – Size ~ 2.17m²
- Zero-Gap
  - Qcells XL white ~460Wp – Size ~ 2.22m²
  - Qcells white ~390Wp – Size ~ 1.89m²
  - Q-cells black ~385Wp – Size ~ 1.89m²
  - others white ~460Wp – Size ~ 2.24m²
  - Others black ~ 380Wp – Size ~ 1.91m²
- Shingled cells
  - white~410Wp – Size ~ 2.08m²
- Larger Cell modules → Cut 210mm cells
  - white 500Wp – Size ~ 2.39m²

THE PATH TOWARDS HIGH DENSITY PV MODULES

MARKET: W_P → W_P/m^2

- Standard
  - white ~400Wp – Size ~ 2.01m² → 199,0 Wp/m² (w)
  - black ~ 325Wp – Size ~ 1.70m² → 191,1 Wp/m² (b) → "black loss" ~3-4 %
- Small Gaps and Paving
  - ~450Wp – Size ~ 2.17m² → 207,3 Wp/m² → Gain of ~ 3-4 % (w)
- Zero-Gap
  - Qcells XL white ~460Wp – Size ~ 2.22m² → 207,2 Wp/m² → Gain of ~3-4 % (w)
  - Qcells white ~390Wp – Size ~ 1.89m² → 206,4 Wp/m² → Gain of ~3-4 % (w)
  - Q-cells black ~385Wp – Size ~ 1.89m² → 203,7 Wp/m² → **Gain of ~6-7 %** (b)
  - others white ~460Wp – Size ~ 2.24m² → 205,3Wp/m² → Gain of ~3-4 % (w)
  - Others black ~ 380Wp – Size ~ 1.91m² → 198,9 Wp/m² → Gain of ~4-5% (b)
- Shingled cells
  - white~410Wp – Size ~ 2.08m² → 197,1 Wp/m² → similar to Standard (w)
- Larger Cell modules → Cut 210mm cells
  - white 500Wp – Size ~ 2.39m² → 209,2 Wp/m² → extra gain by size

CONCLUSIONS

ZERO-GAP MODULES

- Show highest power density (Wp/m²)
- High density power modules reduce:
  - Number of modules per installed kWp
  - Required land or roof top area
  - Mounting structure and labor costs
  - CAPEX; can lower LCOE (depends on Cents/Wp)
- Bring new manufacturing and reliability challenges

Thank you for your attention!