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Fraunhofer Institute for Solar Energy Systems ISE

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www.ise.fraunhofer.de
www.moduletec.de
AGENDA

- LCOE or COO?
- CTM-analysis
- Module concepts
LCOE or COO?
Aspects of LCOE

LCOE [€/kWh]
- Manufacturing cost
- Maintenance cost
- Energy
  - Initial power
  - Angular incidence
  - Irrandiance levels
  - Temperature effects
  - Location / weather data
  - Degradation / reliability
LCOE or COO?
Aspects of LCOE

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Energy rating$^{[1,2]}$: module properties + weather data

[2] IEC 61853 standard, in progress
LCOE or COO?
Energy Rating of PV modules

- Laboratory measurements (Fraunhofer CalLab PV modules)
  - STC (1.5% measurement accuracy)
  - Power Rating (15-75°C, 100-1100 W/m²)
  - Spectral response
  - Reflection
  - NOCT

\[
Y_{DC} = H_{POA} \eta_{STC} A_{module} f_{AOI} f_{spectral} f_G f_T f_{stability}
\]

- Comparison of module performance by energy rating for different locations
LCOE or COO?
Aspects of COO

COO [€/W_p]
- Manufacturing cost
- Process cost
- Material cost
- Labour

- Module Power
  - STC

*Nold et al., Proc 27th EUPVSEC, 2012*
Power or efficiency?

**COO-study: Al-BSF vs PERC**

![Bar chart showing the comparison of module costs per Wp for Al-BSF and PERC technologies.](chart)

- **p-mc Al-BSF Strct**: Lower costs in all stages, with a total of 41.2 €/Wp.
- **p-Cz Al-BSF**: Lower costs in all stages, with a total of 43.4 €/Wp.
- **p-mc PERC**: Lower costs in all stages, with a total of 40.4 €/Wp.
- **p-Cz PERC**: Lower costs in all stages, with a total of 42.4 €/Wp.

The chart illustrates the cost breakdown for each technology, highlighting the stages of poly silicon, wafer production, cell production, module production, and total module costs.
Power or efficiency?
COO-study: Al-BSF vs PERC

<table>
<thead>
<tr>
<th></th>
<th>p-mc Al-BSF Strct</th>
<th>p-Cz AlBSF</th>
<th>p-mc PERC</th>
<th>p-Cz PERC</th>
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<tbody>
<tr>
<td>All-in System Costs (€ct/Wp)</td>
<td>81.6</td>
<td>82.8</td>
<td>79.8</td>
<td>80.9</td>
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<td>Module</td>
<td>41.2</td>
<td>43.4</td>
<td>40.4</td>
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<td>Inverter</td>
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<td>Area prop. BOS</td>
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<td>Soft BOS</td>
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<td>Installers Margin</td>
<td>8.5</td>
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CTM-analysis

Method

- Module example
  - Cell 20.35%, 5 W_p
  - 3BB, Glass-Backsheet


www.cell-to-module.com

CTM_p = -4.2 %
CTM-analysis Method

- Module example
  - Cell 20.35%, 5 W<sub>p</sub>
  - 3BB, Glass-Backsheet

Optical losses
- Total cell power (STC): 300.00 W
- Cover reflection (k9): -4.95 W
- Cover absorption (k4): -2.24 W
- Encapsulant reflection (k6): -0.04 W
- Encapsulant absorption (k6): -4.44 W
- Interconnection shading (k7): -1.44 W
- Interconnector coupling (k8): 7.65 W
- Finger coupling (k9): 1.97 W
- Cell coupling (k10): 0.66 W
- Cell interconnection (k11): 4.11 W
- String interconnection (k12): -11.44 W
- Electrical mismatch (k13): -0.57 W
- Junction box and cabling (k14): -1.16 W
- Module power (STC): 287.30 W

Optical gains
- Electrical losses

CTM<sub>p</sub> = -4.2 %

Module concepts
Current developments

- Current developments
  - 4BB, 5BB standard today
  - Half cells
  - Highly transparent EVA
  - 250 µm ribbon
  - Reflective ribbon

Module concepts
Current developments

CTMₚ = +2.7 %
Module concepts
Multi-wire interconnection

- Multi-Busbar
  - Soldering wires onto micro solder pads
  - Close to standard processing using MBB-stringer

- SmartWire
  - Wires embedded in foil
  - Stringing foils to cells
  - Well-suited for temperature-sensitive cells (e.g. HJT)
Module concepts
Conductive adhesives

- Conductive tapes

- Screen-printable ECAs

- Applications
  - Temperature-sensitive cells (e.g. HJT)
  - Busbar-free cells
  - Back-contact modules with conductive backsheet
Module concepts
Shingling interconnection

- Reduction of inactive areas in module, designed for high module efficiencies
- Overlapping busbar-free cell stripes (6-8 per wafer)
- Use of conductive adhesives
- Concept first published in 1960s\(^1\), current activities at major PV players
- R+D effort at Fraunhofer ISE to combine bifaciality and cell shingling for highest efficiencies\(^2\)

Module concepts

Shingling interconnection

Efficiency [%]

-1.48%  -0.69%  -0.35%  -0.16%  0.00%  -0.31%  -0.58%  0.45%  0.18%  0.09%  0.36%  -0.49%  -0.05%  -0.10%  -0.02%

23.20%  23.20%

SmartCalc.CTM

Gains  Losses

20.06%  21.93%
Challenges

- Half cells, shingling
  - cutting process for low edge recombination
  - Processing throughput

- Temperature-sensitive high-efficiency cells, shingling
  - Cost-effective solder alloy / conductive glue

- Multi-wire, XBB
  - Cell metallization < 10 mg Ag
Challenges

- Lead-free solder alloy
  - Triggered by legislation

- BIPV-modules
  - Automated mass-production of customizable modules

- General
  - Standards for optimization towards energy (energy rating)
  - Drivers for high efficiencies, special applications?
Thank you for your attention!

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