FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE

Module Optimization by using SmartCalc.CTM

Ulrich Eitner, Max Mittag,
Martin Heinrich

Fraunhofer Institute for Solar Energy Systems ISE

PV-Days 2017

Halle (Saale), 25.10.2017

www.ise.fraunhofer.de
www.cell-to-module.com

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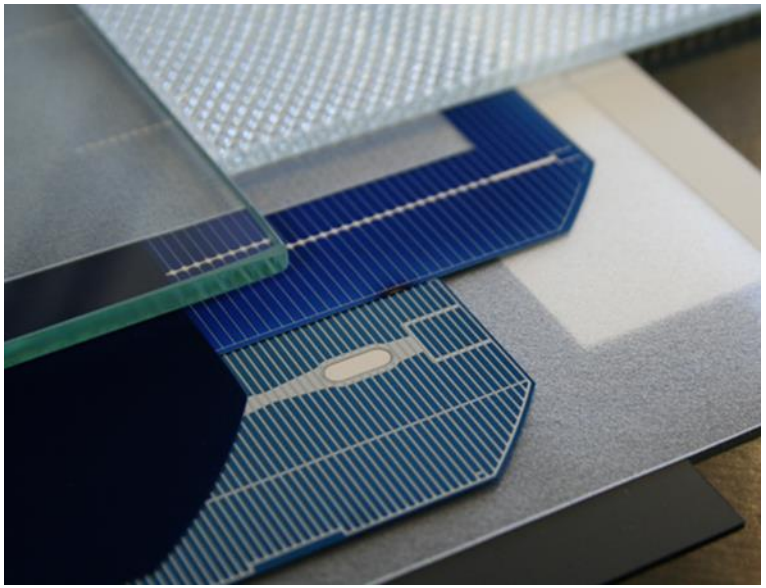
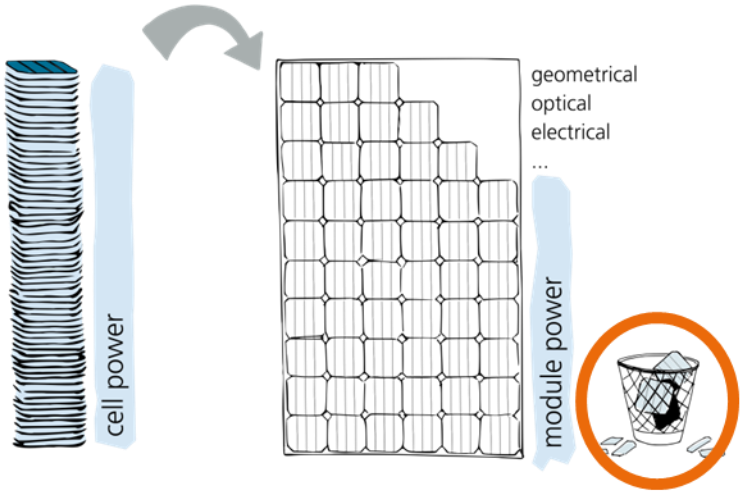
Cell to Module Analysis
Motivation



- Module materials (BOM) and module setup/concept determine power output
- Cell power > module power
- Power losses = financial loss (€/W_p)
- CTM-ratio currently at ~98.5% [1]

→ 1 $ **per module** CTM-loss (275 Wp, 0.25 $/$W_p$)



[1] ITRPV Roadmap 2017, alcaline textured mono cell

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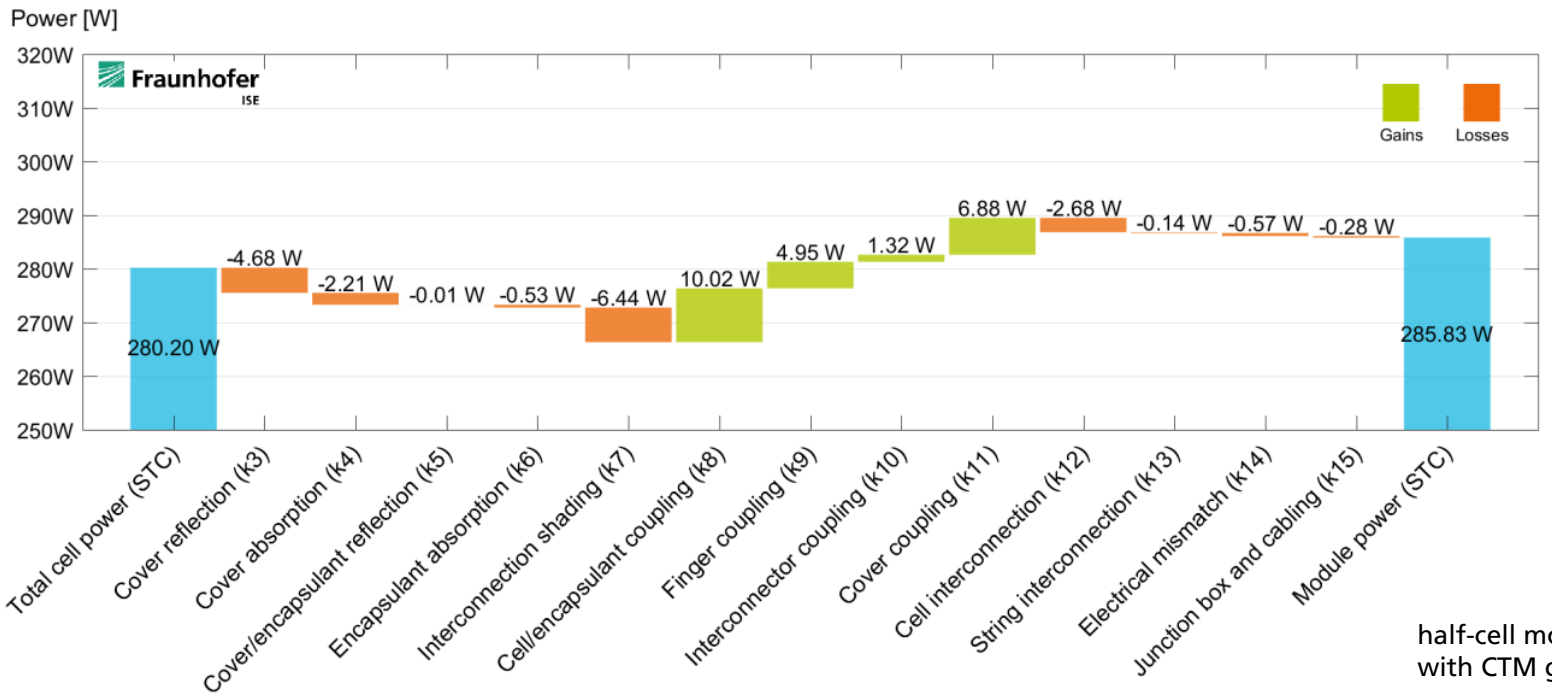
Cell to Module Analysis
Motivation

- Significant CTM-gains possible
- CTM-factors influence each other → optimization of a complex system



half-cell module
with CTM gain

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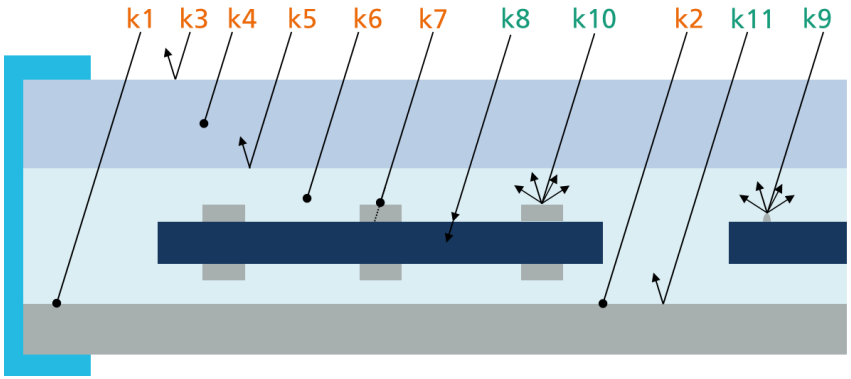
Cell to Module Analysis
Methodology

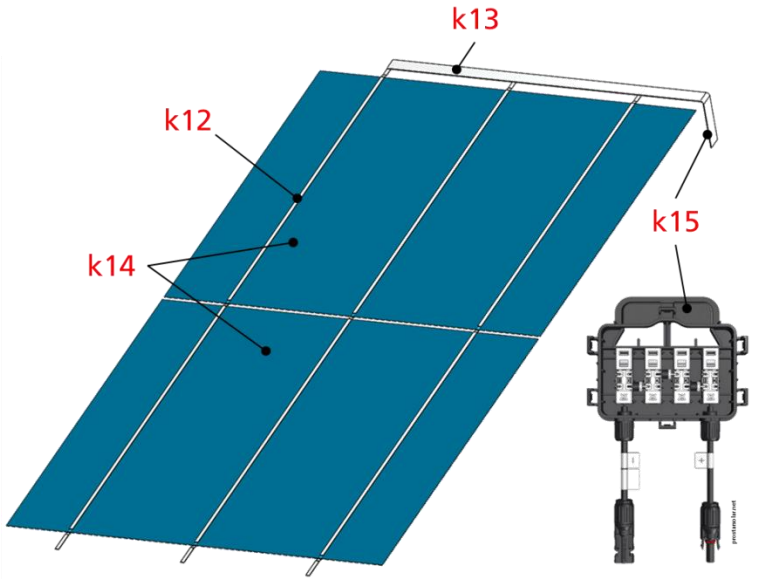
Increasing the CTM-ratio[1-4]

- Unified methodology for CTM modeling [1]



SmartCalc.CTM is cell to module analysis by Fraunhofer ISE

- Characterization procedure
- Calculation of 15 loss factors based on material properties and module setup



gain and loss mechanisms

[1] Haedrich et al., SOLMAT 131 (2014), 14-23
[2] McIntosh et al., IEEE PVSC 2009, 544-549
[3] Peters et al., IEEE JPV 2014, 585-593
[4] Schneider et al., Prog. Photovolt: Res. Appl. 2014; 22:830–837

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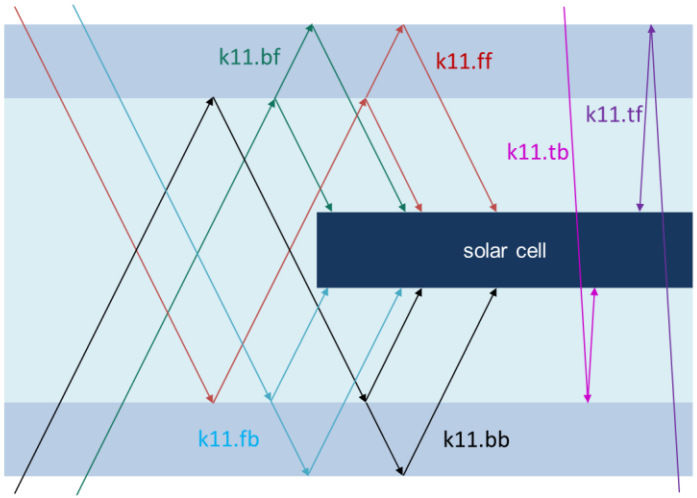
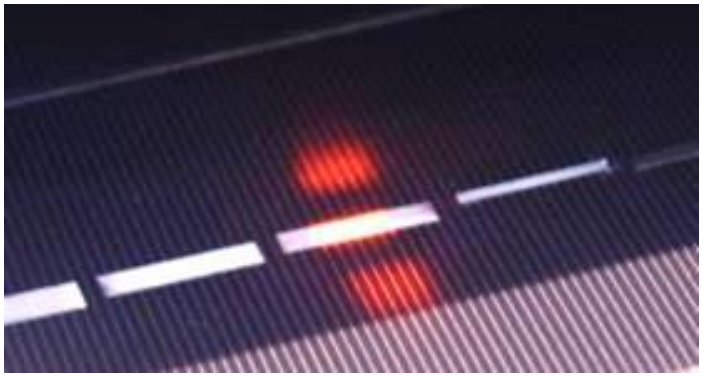
SmartCalc.CTM
Overview I

- Scientific models
  - Analysis of existing modules
  - Performance prediction and evaluation of new technologies



optical gains for bifacial solar cells

- Continuous improvement
  - New module concepts, materials and components
  - New gain & loss factors
  - New measurement methods
  - Alternative calculation models

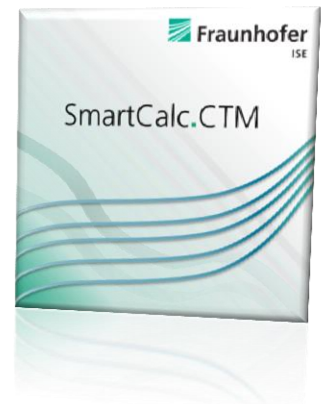


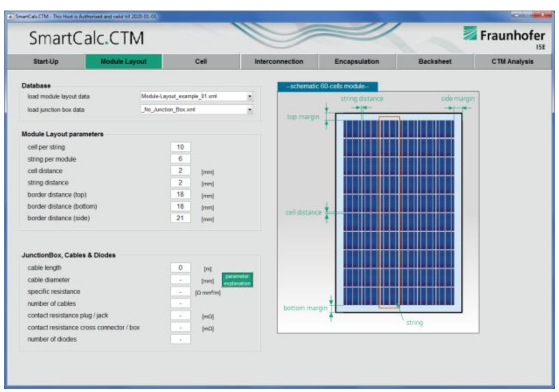
measurement of reflective gains

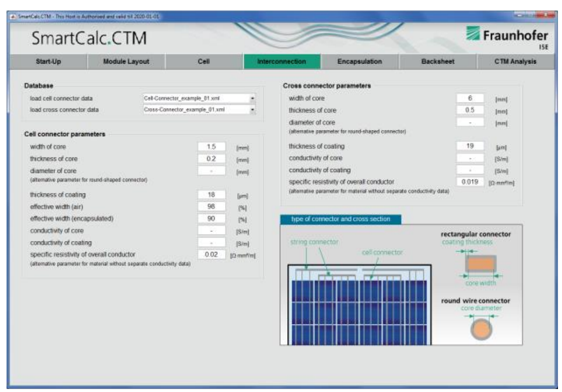
SmartCalc.CTM
Overview II

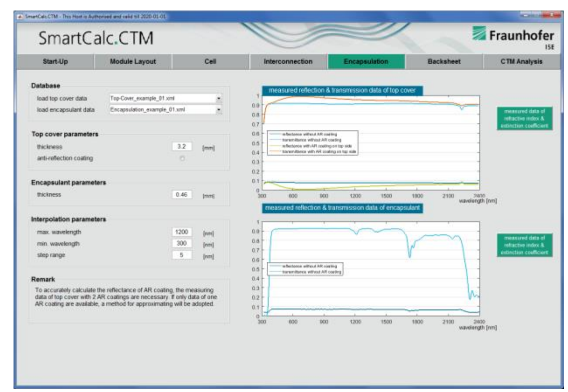
SmartCalc.CTM is a software to analyze gain and loss mechanisms in PV modules

- Accessible user-interface
- Flexible
- Precise
- Validated









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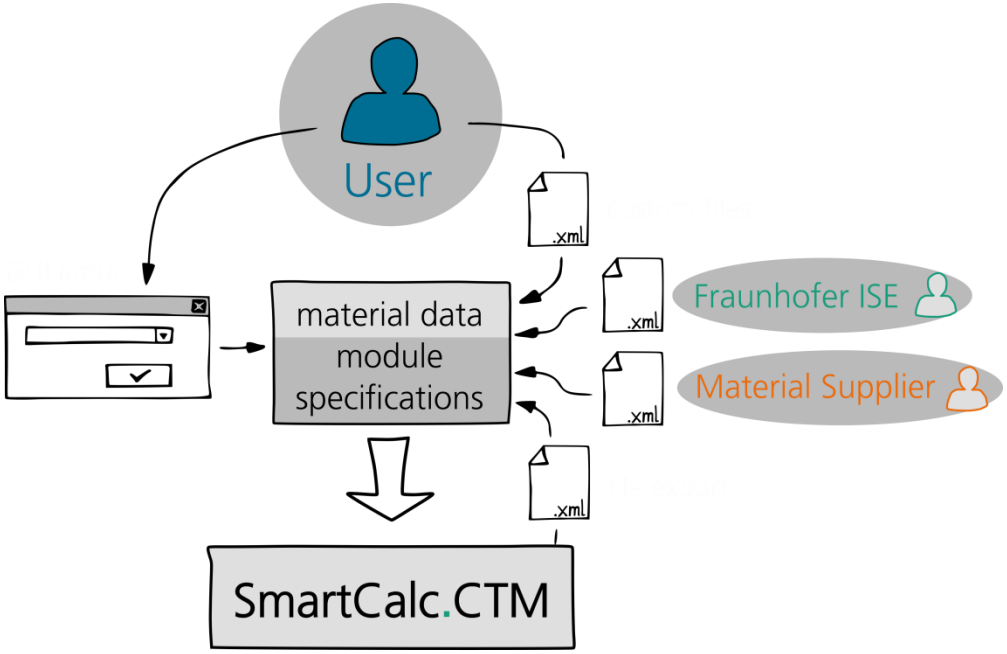
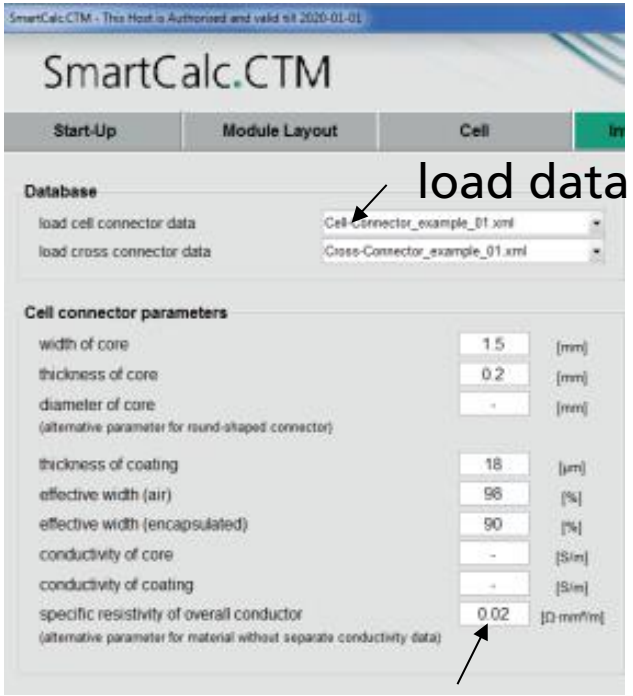
SmartCalc.CTM
Features: Accessibility – Data Input

- Easy use of different data sources





load data files

or enter data in GUI

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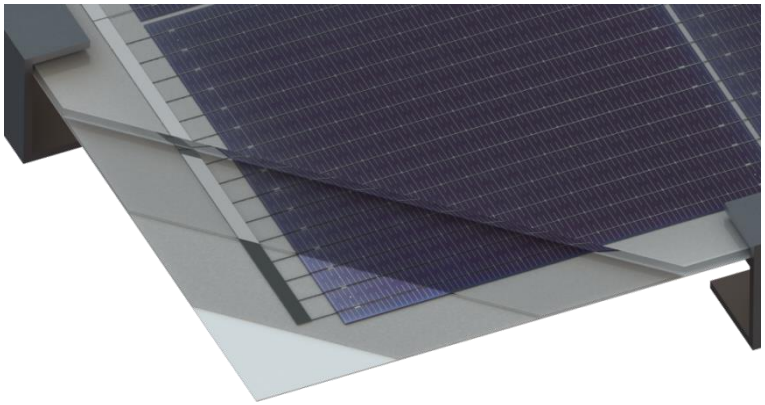
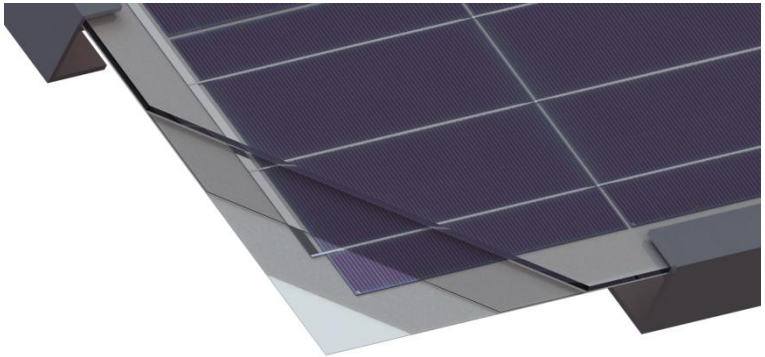
SmartCalc.CTM
Features: Flexibility

- Change module materials
  - Encapsulation, interconnector, ribbons, backsheets, glass etc.
- Change properties of components
  - Thickness, reflectivity, conductivity, geometry etc.
- Change the module layout
  - Number of cells and string etc.
- Change the module concept
  - Glass/backsheet, glass/glass, TPedge, shingled modules etc.





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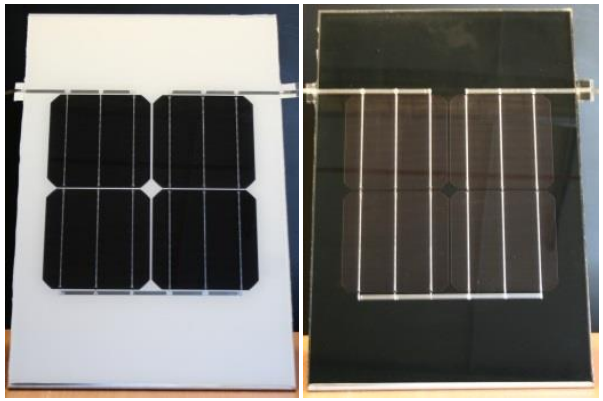
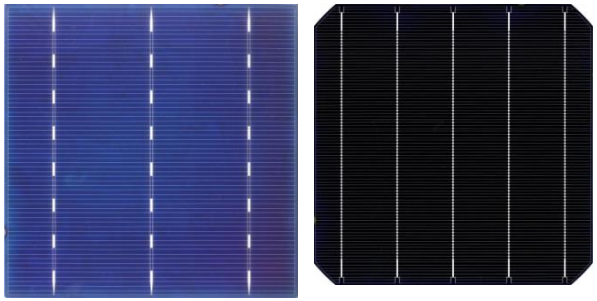
SmartCalc.CTM
Features: Analyze and Optimize

- Analyze and optimize:
  - Back-contact solar cells
  - Variable number of busbars
  - Round wire interconnection
  - Half-cells
  - Glass-glass-modules
  - Black or transparent backsheets
  - Effects of anti-reflective coatings
  - Shingled solar cells
  - …





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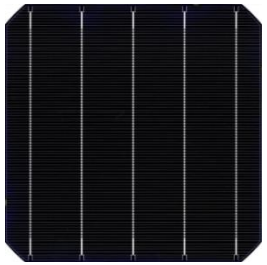
SmartCalc.CTM
Features: Flexibility

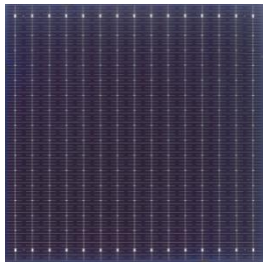
- Strong influence of cell architecture on CTM

conventional cell, 3BB, 156 mm



cell, 5BB, jumbo format: 156.75 mm

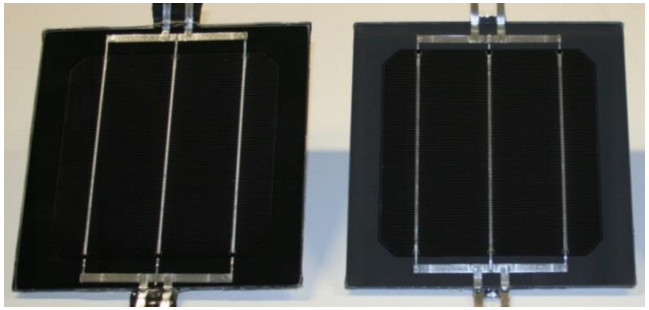
ISC Konstanz Zebra cell, back-contact



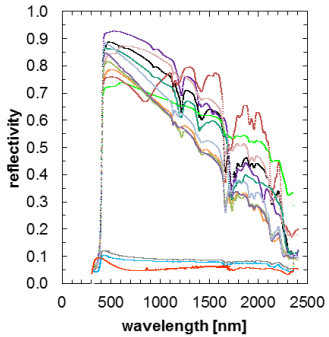
round wire interconnection, 15 BB

SmartCalc.CTM

- High variation in module material properties



different commercially available black backsheets



reflectivity of different commercially available module materials

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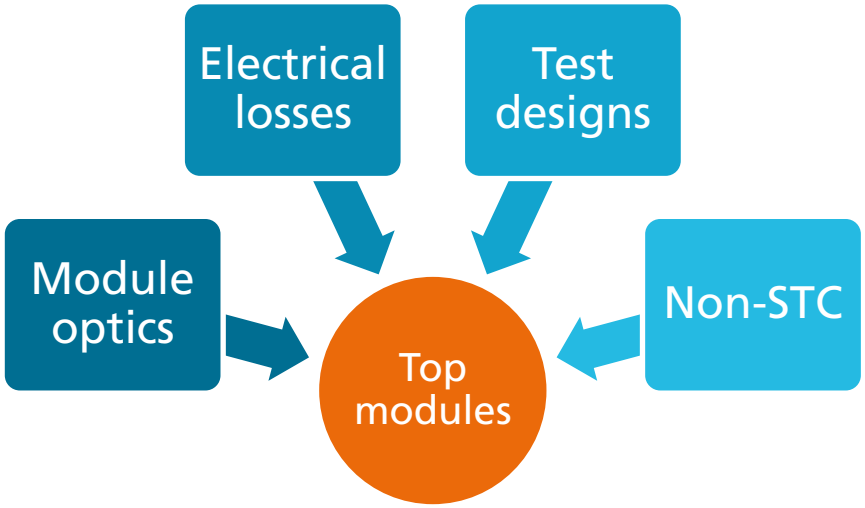
CTM100+ Project

- „Innovative technologies to increase the CTM-ratio for quality PV modules“
- 04/2016 – 03/2019
- Fraunhofer CSP and ISE
- Industrial partners
  - f|solar, Temicon
  - Heckert Solar, SI Module
  - Alu Feron
  - Wavelabs
  - JvG Thoma, Pi4 robotics



CTM100+ Project
Module Optimization

- Module optimization at Heckert Solar
- Module performance increase of 0.5% realized so far
- “SmartCalc.CTM enables us to carry out detailed analyzes and at the same time reduce the costs for prototypes.”

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Heckert Solar reduces cell-to-module losses using Fraunhofer ISE’s software

By Mark Osborne | Aug 29, 2017 9:34 AM BST | 0 | Share

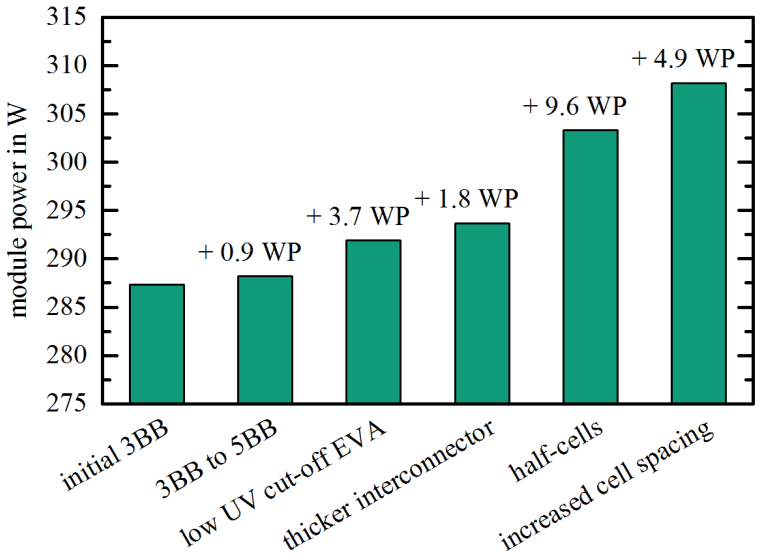
SmartCalc.CTM

Gefördert durch: Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des Deutschen Bundestages

Heckert Solar noted that its had been involved in the software project since 2016 achieved initial results with a performance increase of around 0.5% for its modules. Image: Fraunhofer ISE

CTM100+ Project
Current developments

- Current developments[1]
  - 4BB, 5BB standard today
  - Half cells
  - Highly transparent EVA
  - 250 µm ribbon
  - Reflective ribbon



[1] Mittag, M. et al., Photovoltaics International 36, 2017

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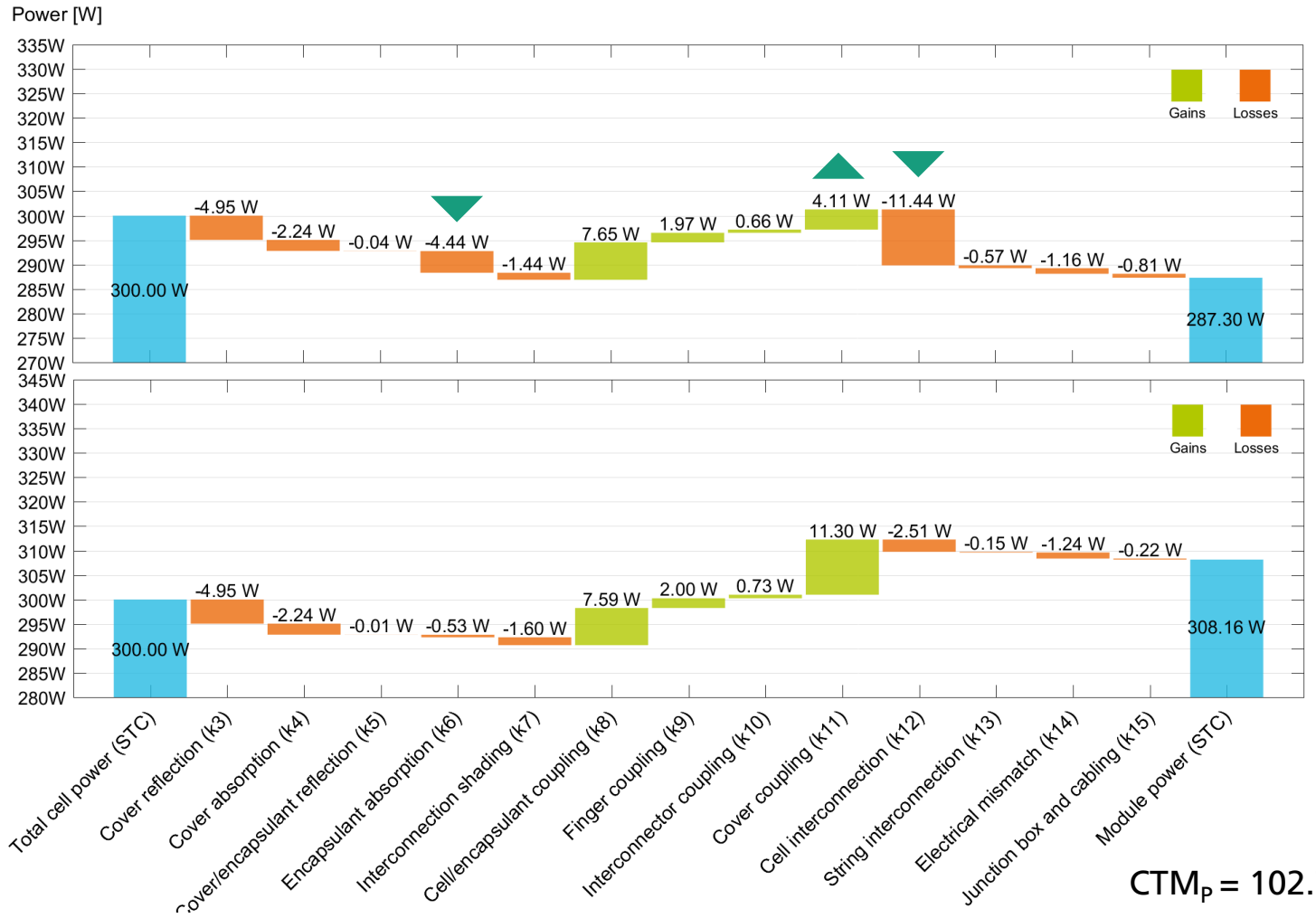
CTM100+ Project
Current developments



CTM_P = 102.7 %

[1] Mittag, M. et al., Photovoltaics International 36, 2017

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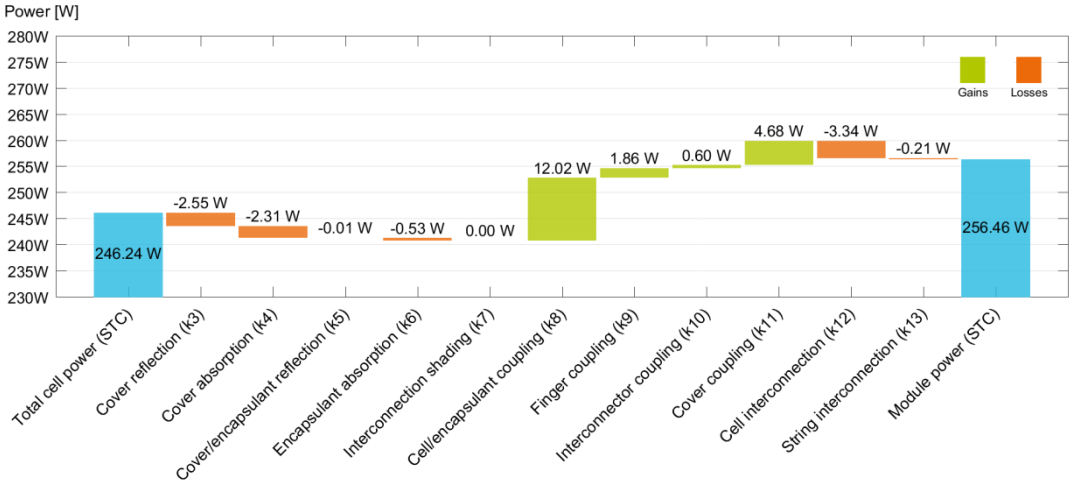
Module examples
Half-cell module, CTM100+ project



	$\sum P_{Cells}$ [W]	P_{Module} [W]	Eta [%]
4BB half-cell module	246.24 W	258.86 W	105.1%

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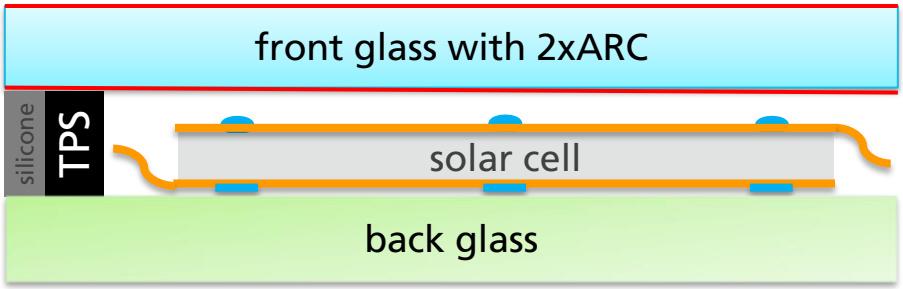
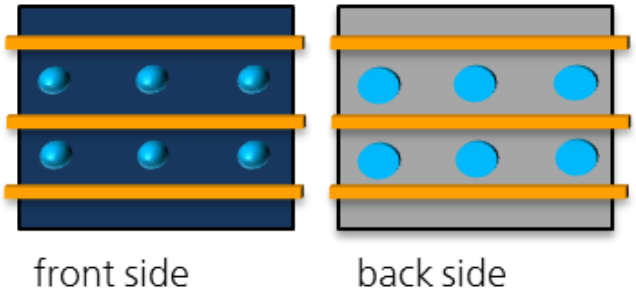
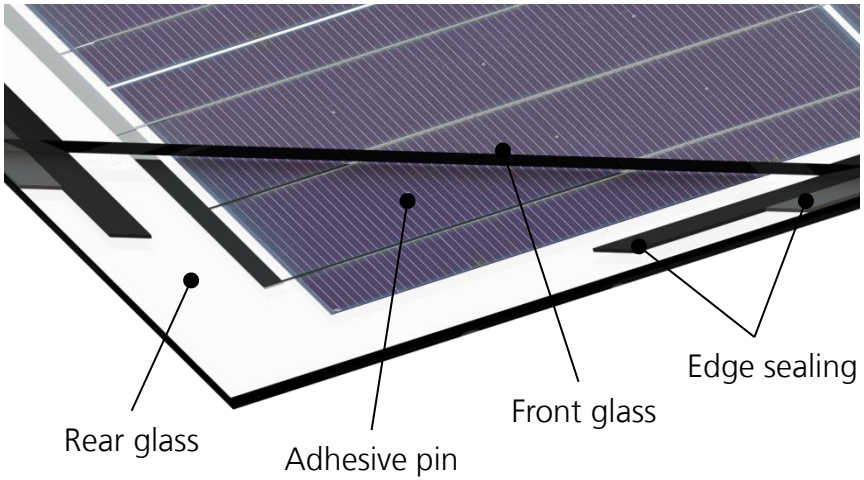
Module examples
TPedge



- TPedge[1] is
  - a glass-glass module
  - not using polymer encapsulation or backsheet foils
  - air filled
  - edge sealed



- Solar cells are fixed with UV-curing pins on back glass



[1] Mittag, M. et al, "TPedge: Qualification of a Gas-filled, Encapsulation-free Glass-Glass Photovoltaic Module", 31st EUPVSEC, Hamburg, 2015

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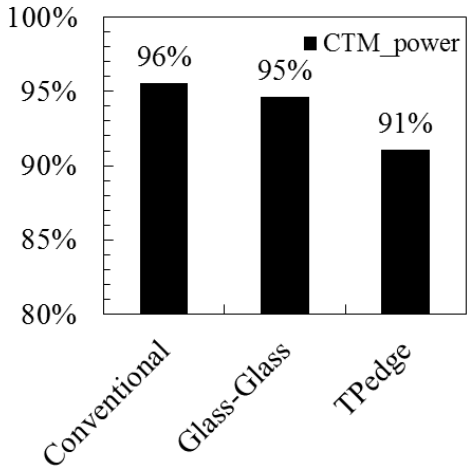
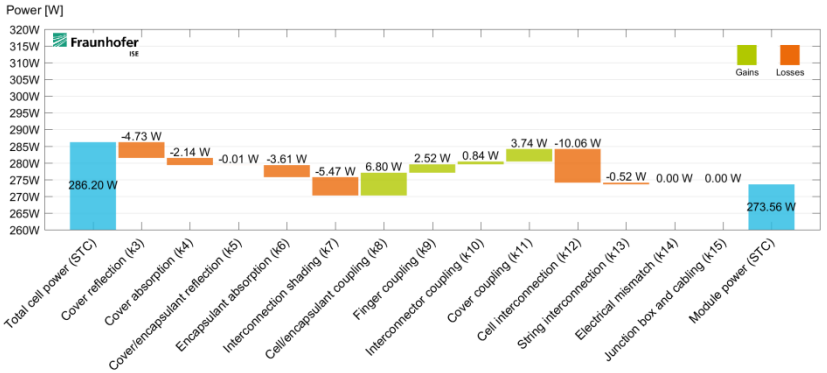
Module examples
TPedge

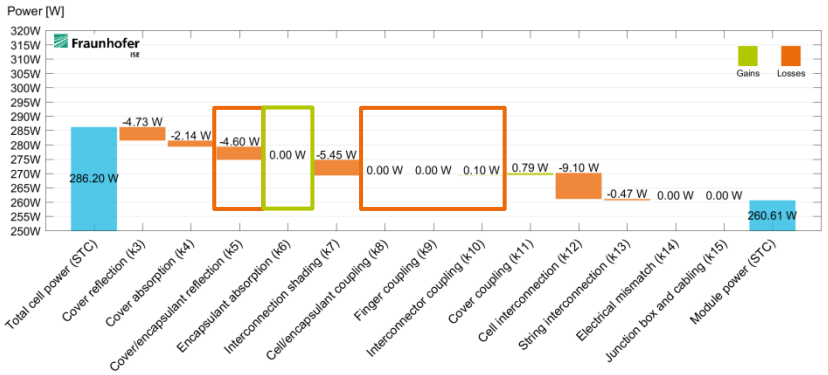
- CTM-analysis shows
  - Increased reflection losses of TPedge
  - Reduced coupling gains
  - Reduced absorption losses



Conventional module



TPedge module



[1] Mittag, M. et al, "TPedge: Progress on Cost-Efficient and Durable Edge-Sealed PV Modules", 33rd EUPVSEC, Amsterdam, 2017

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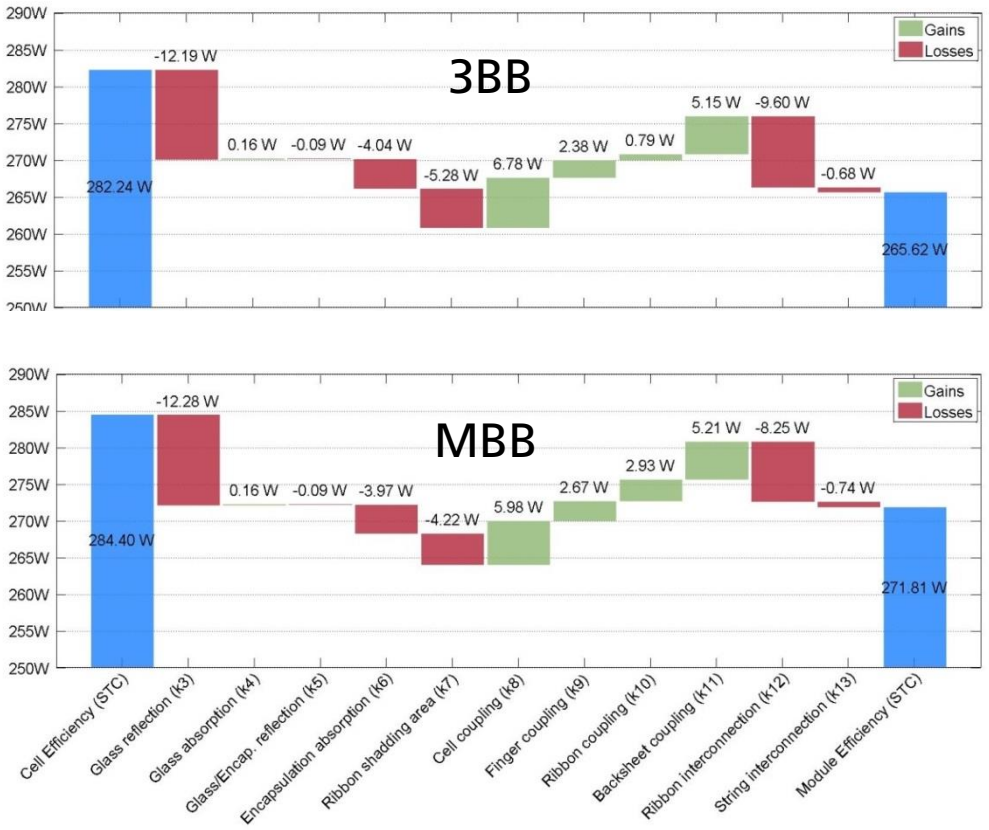
Module examples
MultiWire

- $\eta_{Cell,\ 3BB} = 19{,}3\ \%$
- $\eta_{Cell,\ MBB} = 19{,}5\ \%$



ΔP_{MBB}= 6.2 W (2.3%)

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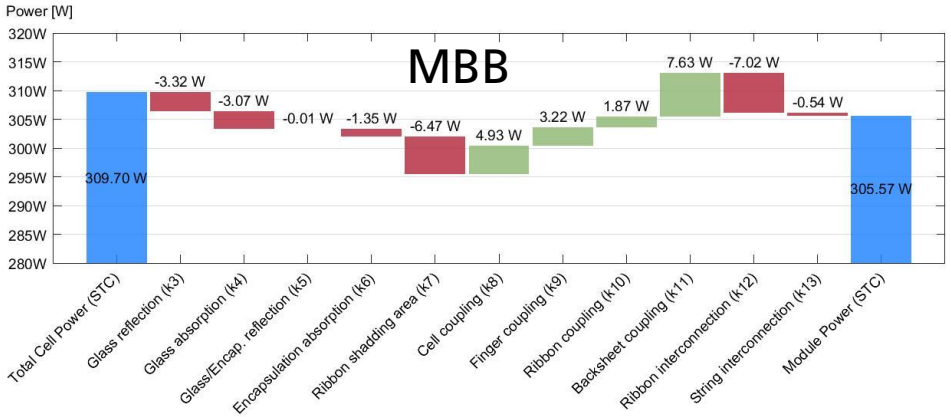
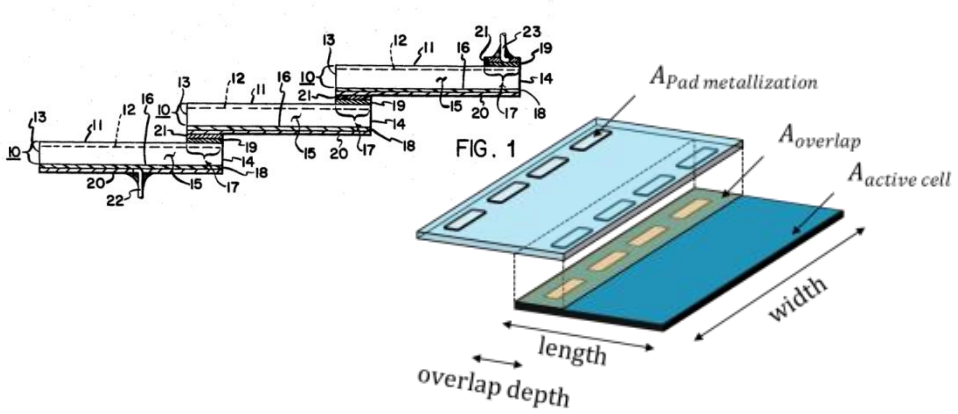
Module examples
MultiWire

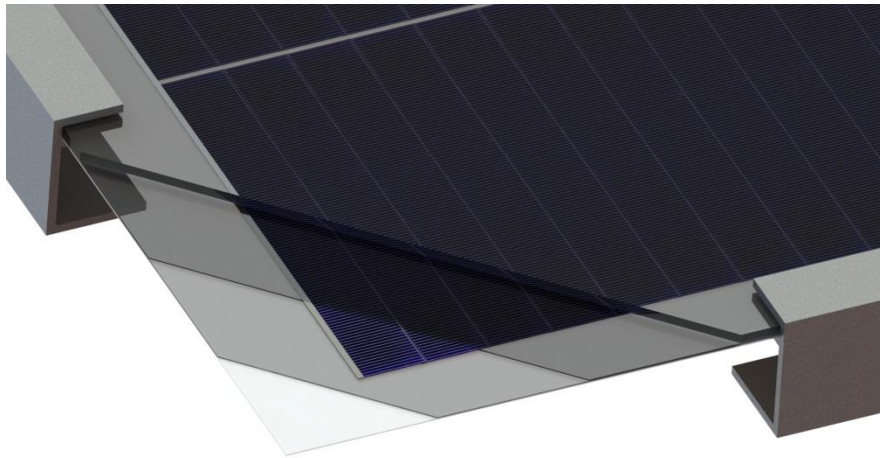


	P_{mpp} [W]	FF [%]	Eta [%]
MBB Top-Module	306.2	77.45	18.39

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]

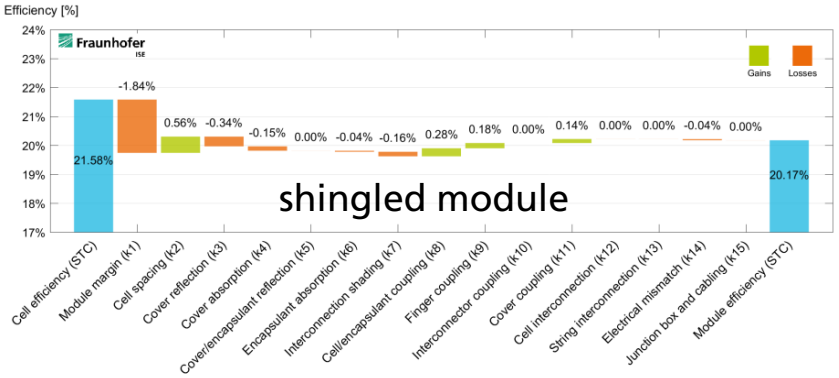


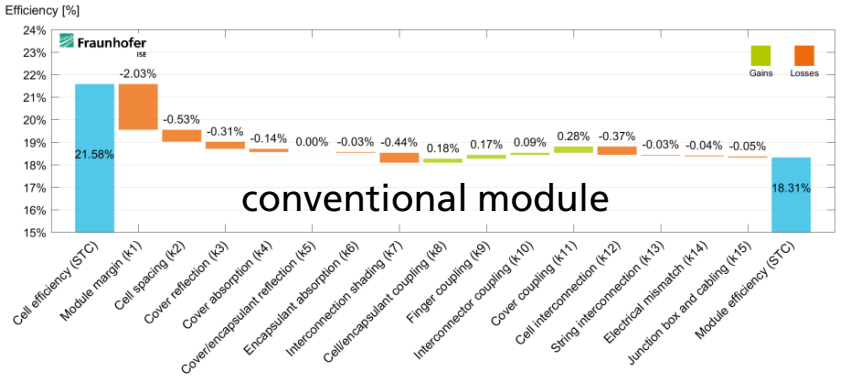


[1] Dickson, D.C. jr., US Patent 2938938, 1960
[2] Wöhrle, N. et al., Photovoltaics International 36, 2017

Comparative CTM-Analysis of Modules
Efficiency

- Gains compared to a conventional module





	shingle	conventional	Δ
η_{cell}	21.58%		±0%
η_{module}	20.17%	18.31%	+10.1%
$\Delta\eta$	-1.41%$_{abs}$	-3.27%$_{abs}$	+1.86%$_{abs}$
CTM_{η}	0.935	0.848	+10.3%

[1] Mittag, M. et al., "Cell-to-Module Analysis for PV Modules with Shingled Solar Cells", Proc 44th IEEE PVSC 2017

Status and Outlook
CTM-Analysis

SmartCalc.CTM
www.cell-to-module.com

- Free demo version available
  - For software evaluation
  - No support, Limited features, 3 months
- Full version
  - Annual license, full access to all features
  - Consulting & support included
- Variety of Module concept suited for > 300 W and > 20% Module efficiency

Thank you for your attention!

Fraunhofer Institute for Solar Energy Systems ISE

Ulrich Eitner

www.cell-to-module.com

www.ise.fraunhofer.de

ctm@ise.fraunhofer.de

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Contact & Additional Information

- www.cell-to-module.com
- www.blog.innovation4e.de/en
- mail: CTM@ise.fraunhofer.de

- Selected Publications
  - Haedrich et al., „Unified methodology for determining CTM ratios: Systematic prediction of module power", SiliconPV 2014
  - Mittag et al., "Cell-to-Module Analysis for PV Modules with Shingled Solar Cells", IEEE PVSC 2017
  - Mittag et al., EUPVSEC, Amsterdam 2017
  - PVPMC Workshop, Freiburg 2016 / Weihai 2017