# RECENT RESULTS FOR THE DEPLOYMENT OF SILICON HETEROJUNCTION PRODUCTION LINES AT ENEL GREEN POWER: EFFECT OF THE NUMBER OF BUSBARS

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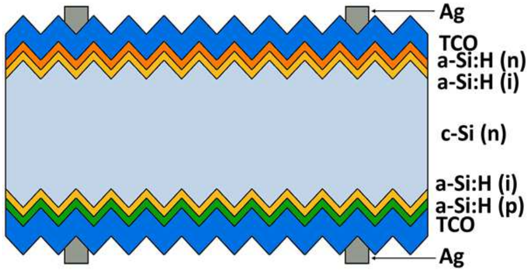
- **a-Si:H/c-Si heterojunction technology (SHJ)**




- Allows record efficiencies of 25,1% (Both-side contacted) [1] and 26,63% (Back-Contacted) [2]
- Industrially mature with 1.5GW installed and 12 more announced [3]

- **CEA-INES SHJ background**
  - More than 10 years experience on SHJ
  - Versatile cells and modules pilot lines with industrial and R&D tools [4]
  - Compatibility with busbars (BB) and SmartWire (SWCT) designs

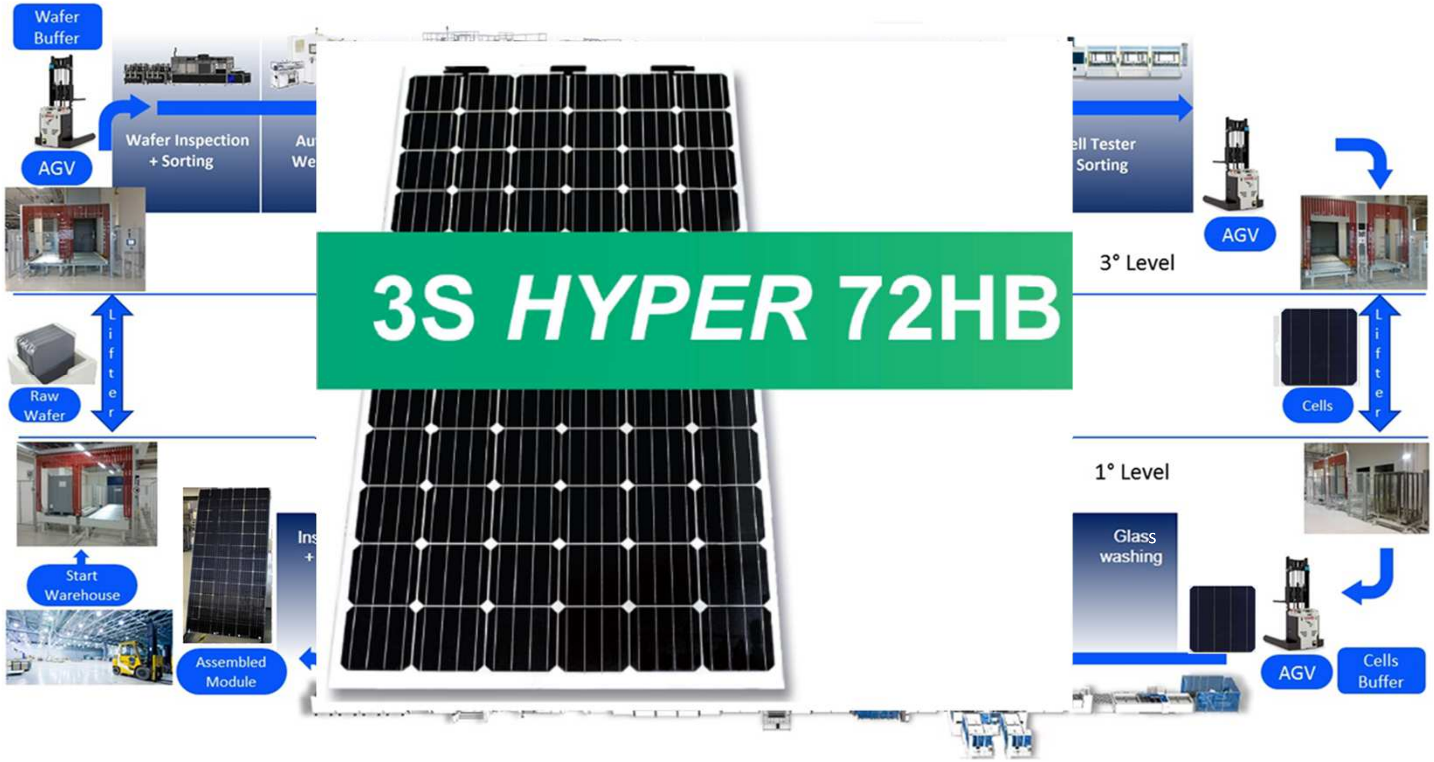
- **EGP SHJ project**
  - 200MWp SHJ cells and assembly lines in Catania, Sicily
  - Fully automated lines

[1] Adachi et al., Applied Physics Letter 107, 23 (2015)
[2] Yoshikawa et al., Nature Energy 2 (2017)
[3] ITRPV, 2019
[4] A.Danel et al., Proceedings of 33rd EUPVSEC (2017)

# General context

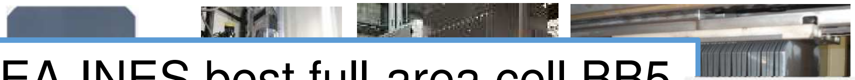
# General context

- **EGP SHJ production lines in Catania**

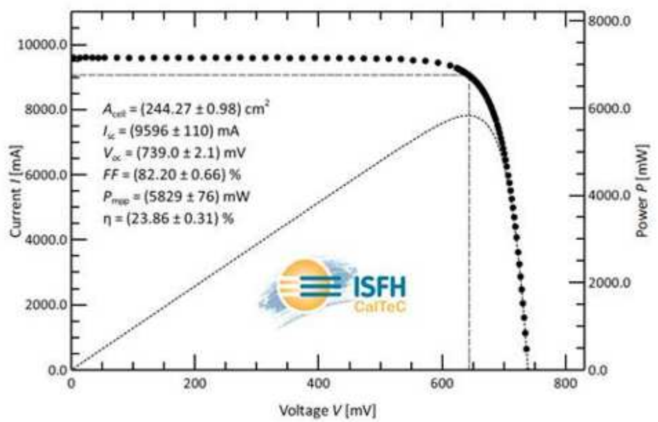



**→ Use of CEA-INES SHJ facilities to speed-up the EGP project**

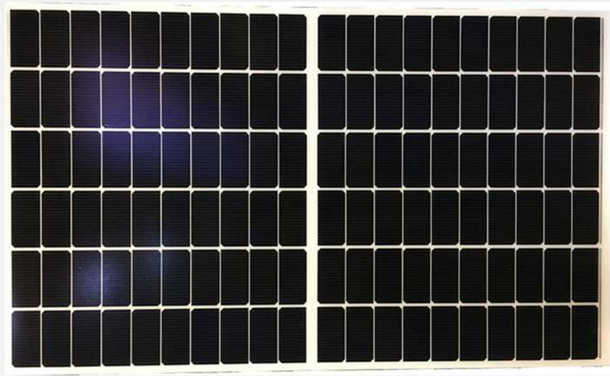
- **CEA-INES SHJ facilities**



CEA-INES best full-area cell BB5 design:




**CZ Ingot/ Wafering**



December 2018 : 348 W
for 120 Half-Cells (SWCT)
(Equivalent 60 cells module)

**Outdoor PV systems**

**3KWp / systems**

# Objectives of this work

- **Strategies to decrease the costs at the cell level**
  - Use thinner wafers
  - Reduce silver paste consumption → -40mg [5]
  - Reduce In consumption
  - Ensure low scrap
  - Increase efficiency → +0.1% [5]

**BB4 → BB5**

- **Strategies to decrease the costs at the module level**
  - Reduce electrical contact adhesive (ECA) consumption → +8-20mg [5]
  - Improve reliability
  - Increase efficiency

**What is the impact of moving from BB4 to BB5 on:**

- Costs?
- Cell efficiency?
- Modules efficiencies?
- reliability?

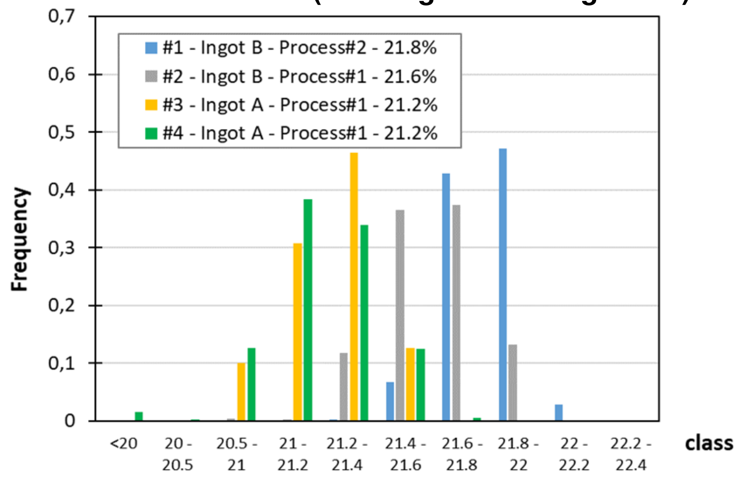
} Will be addressed in this talk

[5] A. Faes et al. PV International Sept 2018

- **Example of efficiency distribution for 4 SHJ cells batches produced on CEA-INES pilot line with BB4 design (> 2000 cells/batch)**
  - Ingot A - res: 1 – 7 Ω.cm; bulk lifetime > 2 ms
  - Ingot B - res: 0.2 - 2 Ω.cm; bulk lifetime >500 µs

| | Ingot B | | Ingot A | |
|---|---|---|---|---|
| | **#1** | **#2** | **#3** | **#4** |
| **$V_{oc}$ (mV)** | 729.4 | 732.1 | 730.6 | 729.3 |
| **$J_{sc}$ (mA/cm$^2$)** | 37.6 | 37.5 | 37.7 | 37.5 |
| **FF (%)** | 79.4 | 78.7 | 77.1 | 77.5 |
| **Eff. (%)** | 21.8 | 21.6 | 21.2 | 21.2 |

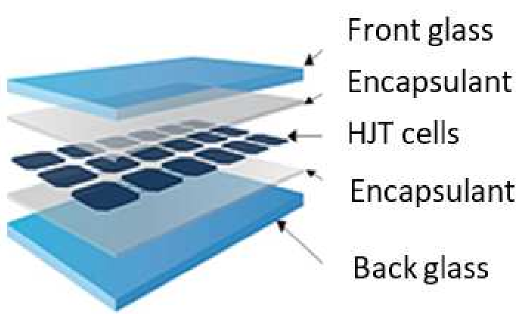
**Bifacial BB4 cells (IV using dark background)**

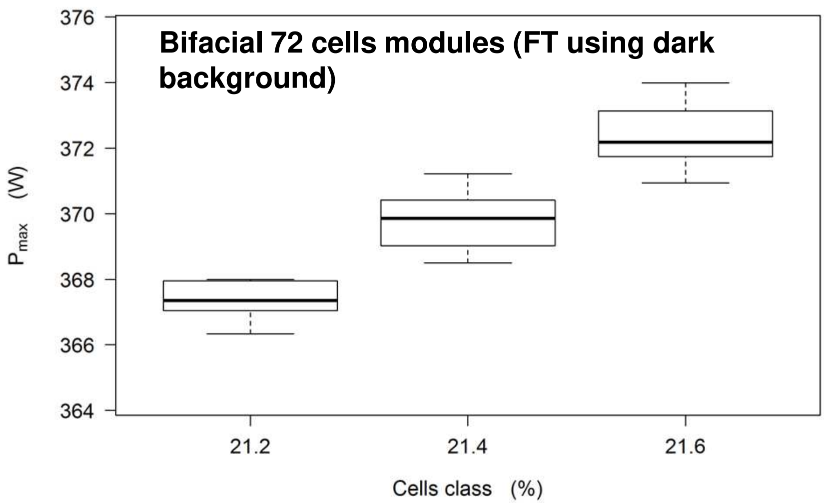



- Cells produced early 2018 mainly for EGP tools test acceptance purpose
- Narrow distributions with >21.6% (resp. 21.2%) average efficiency depending on the ingot used
- Impact of ingot properties presented elsewhere [6]

[6] G. Condorelli et al., proceedings of IEEE 7th WCPE (2018)

- **Examples of $P_{max}$ distribution of modules produced at CEA-INES pilot line with 72 SHJ cells (BB4 design)**
  - More than 20 modules produced
  - Very low number of visual defects and micro-cracks
  - Flash tests performed using dark background




- Narrow distributions with values in the range 366W to 374W
- $P_{max}$ mainly governed by the cells class efficiency
- CTM ratio close to 0.98

# Going from BB4 to BB5 modules

- **Some cells from batch #1 also printed with BB5 design**
- **Bifacial 60 cells modules produced using SHJ cells with BB4 or BB5 design. Same module design.**

**Average IV parameters with dark background**

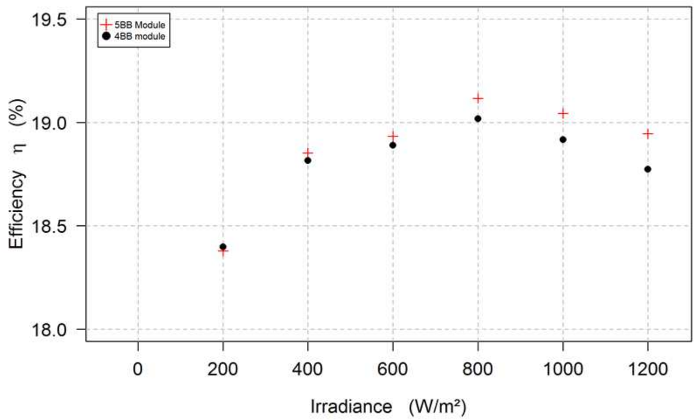
- +0.8% abs. FF increase (79.4%→ 80.2%) and ~+0.2 abs. efficiency increase related to series resistance reduction
- Similar values for every IV parameter except for the FF
- FF improved by 0.7% and 0.6% abs. respectively for the front and back sides measurements
- +2W for the module with BB5 design

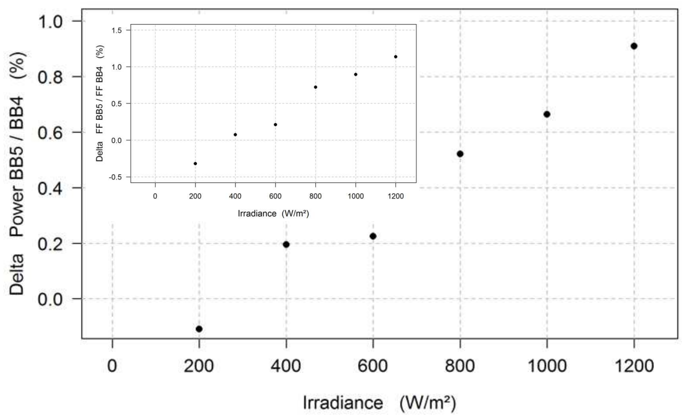
**→ The gain observed at the cell level still present at the module level !**

**What behavior under variable illumination ?**

# Going from BB4 to BB5 modules

- **Study of the 60 cells modules power in the 0.2 – 1.2 Suns range (dark background)**



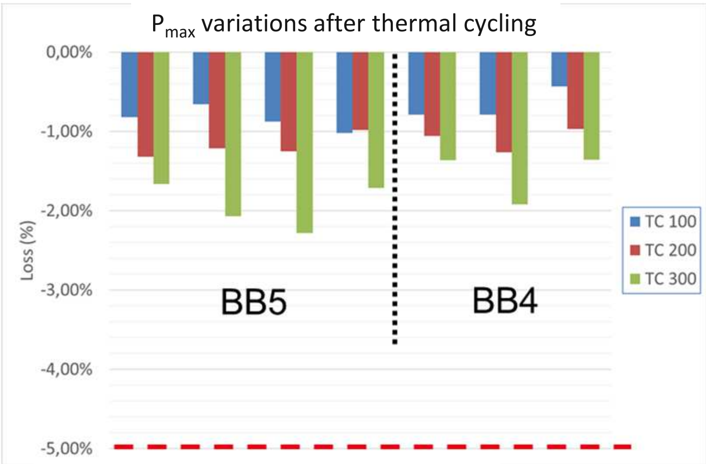

- Efficiency gain for BB5 design from 0.4 to 1.2 Suns
- Power increase with increased illumination mainly driven by FF

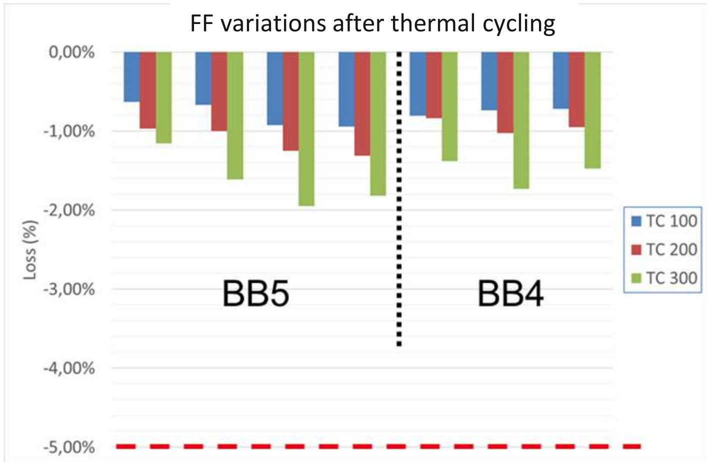
**→ The gain observed is present on the full illumination range !**

# Going from BB4 to BB5 modules



- **Reliability testing of the BB4 and BB5 designs**
  - Several 2*2 cells modules produced with BB4 and BB5 SHJ cells
  - Up to 300 thermal cycles (TC) performed – 1.5 times the IEC standard

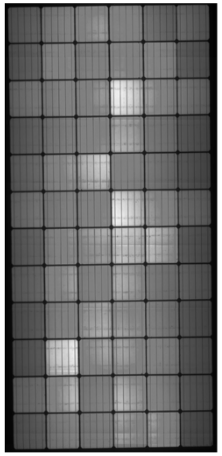


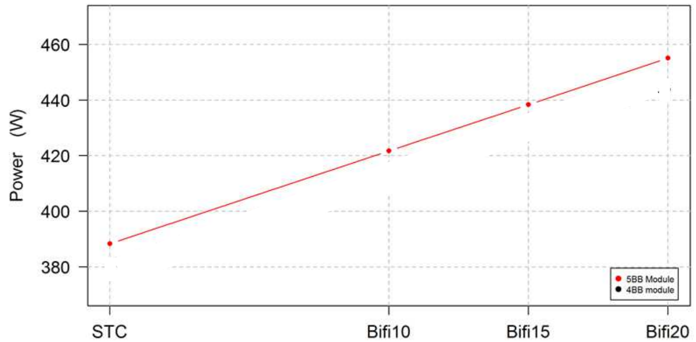

- $P_{max}$ losses <1% after TC100 and below 2% (average) after TC300 for both BB4 and BB5 configurations
- $P_{max}$ losses are related to FF losses

→ **Reliability is ok for both configurations**

# Bifacial 72 cells module produced with BB5 design



| Module | Side | $P_{max}$ ($W_c$) | $V_{oc}$ (V) | $I_{sc}$ (A) | FF (%) |
|---|---|---|---|---|---|
| **Best module** | Front side | 388.4 | 53.1 | 9.27 | 78.9 |
| | Back side | 341.5 | 53.0 | 8.18 | 78.8 |




- Bifaciality ratio[7,8] equal to 87.1%.
- $P_{max}$ of 388.4W and 421.7W respectively at STC (dark background) and at Bifi10

[7] Determined according to IEC 60904-1-2:2019
[8] Bifaciality coefficient study presented by A. Danel (2CO.10.6)

# Conclusions

- **Strong Know-How and partnership for the deployment of the a-Si:H/c-Si technology in Europe**
  - Cells efficiencies higher than 23.8% demonstrated at the pilot line level on full area M2 wafers with BB5 design
  - Modules efficiencies up to 348Wp (120 half-cells) demonstrated with SmartWire Connection Technology (monofacial module)
  - First European SHJ production line of 200MW at Enel Green Power site in Catania, Sicily

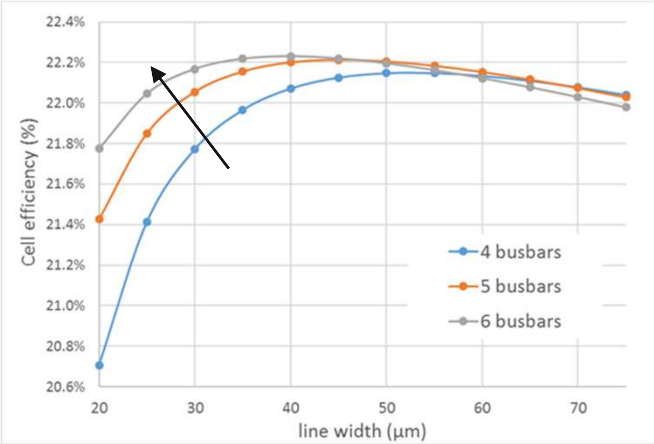
- **Going from BB4 to BB5 design**
  - Enables cell fill factor / efficiency gain related to series resistance reduction.
  - Gain confirmed at the module level and increasing with illumination intensity
  - TC tests performed on 2*2 cells modules show similar trends for BB4 and BB5 with $\Delta P_{max}$ < 2% after 1.5 times IEC std

→ **Path is open for industrialization of the BB5 design at EGP**

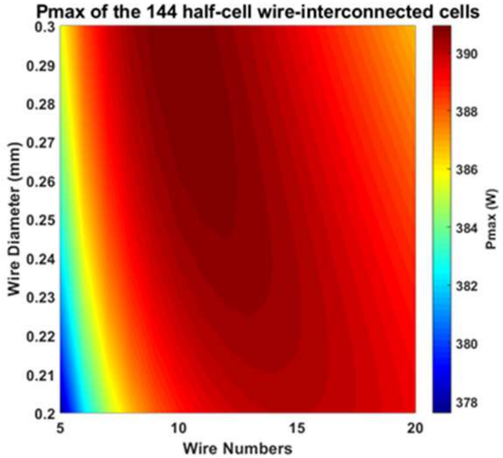
# Perspectives

- **What's next?**
  - BBXX? / SWCT?

**Numerical modeling based on Rs breakdown analysis for a M2 size SHJ cell (Busbars)[9]**




**Numerical modeling at the module level (SWCT)[10]**




→ Need to consider the cell size ($I_{mpp}$), metal contacting properties & manufacturing costs

- More discussion on possible next steps in the following talk (D. Muñoz)

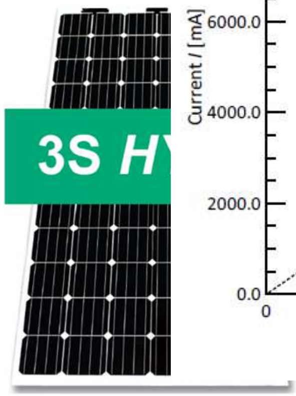

[9] L. Basset et al. presented at PVTC conference (2018)
[10] J. Aymard et al. presented at EUPVSEC (2018)

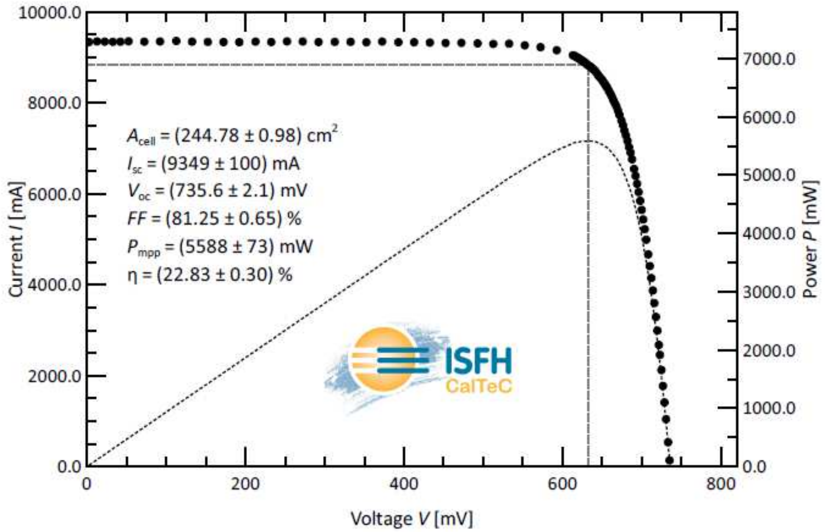
- **Recent news from EGP lines**

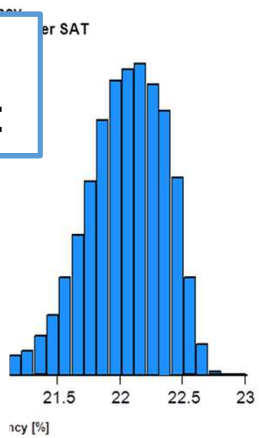
**KPI Targets:**

- 22
- *Pa*
- Ce
- *38*
- CTM >

EGP full-area cell BB4 design from production line, no process optimization:




or:

See tomorrow 2DV.2.74

# Thanks for your attention

**Acknowledgements:**
***EGP team, CEA SHJ cells and modules pilot lines teams***

AUTOMATED PHOTOVOLTAIC CELL AND MODULE INDUSTRIAL PRODUCTION
TO REGAIN AND SECURE EUROPEAN RENEWABLE ENERGY MARKET

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 745601

# General context

| | Soldering | | | ECA-gluing | | | Wire interconnection | |
|---|---|---|---|---|---|---|---|---|
| | 4BB | 5BB | 6BB | 4BB | 5BB | 6BB | Certified | Optimized |
| Front mg | 165 | 155 | 145 | 75 | 70 | 65 | 40 | 20 |
| Back mg | 255 | 220 | 190 | 170 | 135 | 110 | 60 | 40 |
| Total mg | 420 | 375 | 335 | 245 | 205 | 175 | 100 | 60 |

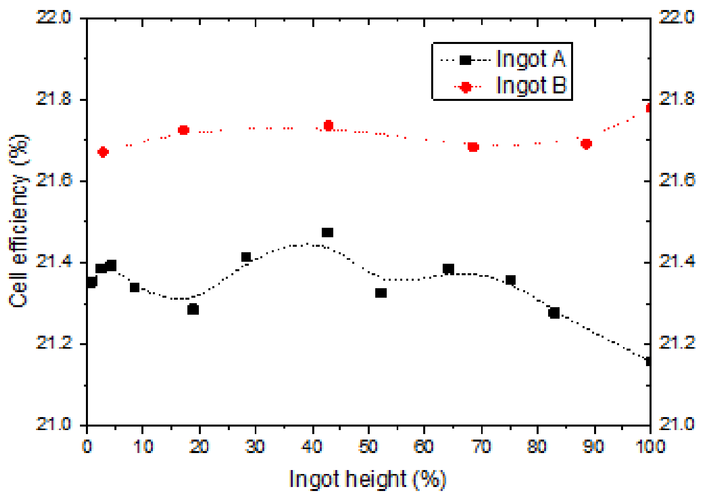
**Table 1. Screen-printed silver paste deposited mass at front and backside for 4, 5, 6 busbars for soldering, electrical conductive adhesive (ECA) gluing and wire interconnection grid design ("certified" can pass five times IEC reliability test and "optimized" for lower silver usage).**

| | Print + Soldering | | | Print + ECA-gluing | | | Print + SWCT | | Plating + soldering | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cell Efficiency (%) | 4BB | 5BB | 6BB | 4BB | 5BB | 6BB | Certified | Optimized | 4BB | 5BB | 6BB |
| | 22.4 | 22.5 | 22.7 | 23.0 | 23.1 | 23.2 | 22.8 | 23.0 | 22.7 | 22.7 | 22.7 |
| CTM performance | 1.01 | 1.01 | 1.01 | 1.00 | 1.00 | 1.00 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |
| Module power (Wp) | 398 | 400 | 403 | 404 | 406 | 408 | 405 | 408 | 403 | 403 | 403 |
| Module power Bifi20 (Wp) | 470 | 472 | 476 | 477 | 479 | 482 | 478 | 482 | 476 | 476 | 476 |

**Table 3. Performance of the cells done by screen-printing and plating with different grid design, module with 72 cells in glass/glass configuration and the respective cell-to-module (CTM) factor. Module power is calculated for a bifacial module with 20% power from the backside due to the albedo (Bifi20). Module bifaciality is 90%.**

[5] A. Faes et al. PV International Sept 2018

- **Efficiency distribution for each SHJ cells batch produced on CEA-INES pilot line with BB4 design (> 2000 cells/batch)**

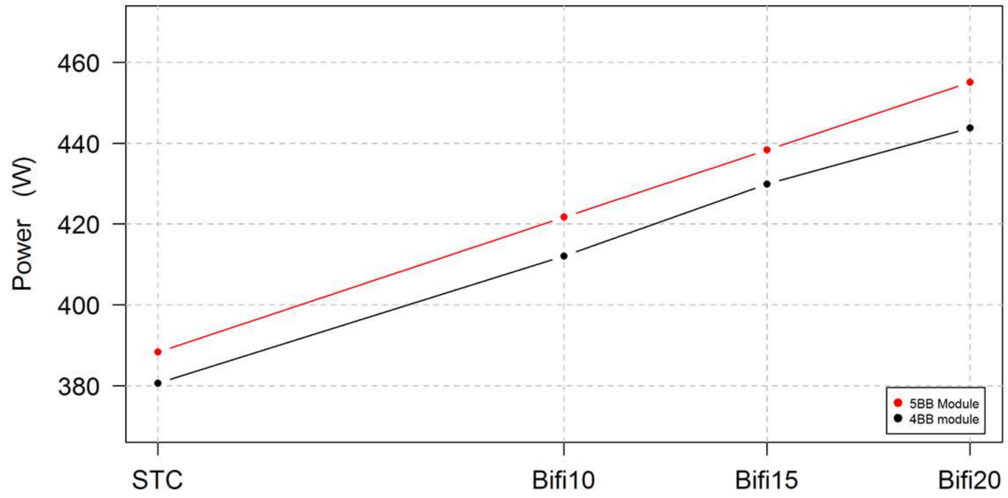



- Impact of ingot properties studied elsewhere [6]
- Some cells from batch #1 also printed with BB5 design

[6] G. Condorelli et al., proceedings of IEEE 7th WCPE (2018)

# Going from BB4 to BB5 modules

- **Bifacial 72 cells modules produced with BB4 and BB5 designs**
  - $G_E$ method performed for the record modules




- $P_{max}$ of 421.7W at Bifi10 (i.e. equivalent illumination contribution of 100W/m² at the module backside) for the best 2018 module
- Study on the optimization of the bifaciality coefficient was presented by A. Danel (2CO.10.6)