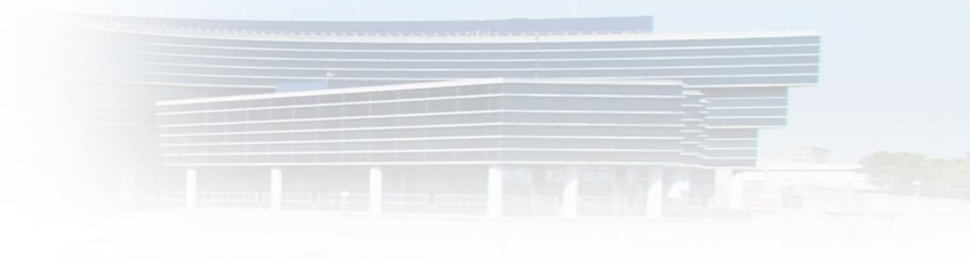


Silicon Hetero-Junction Technology a New Opportunity for PV Manufacturing in Europe

Anna Battaglia
3SUN R&D – Enel Green Power Innovation & Sustainability

SiliconPV 8th International Conference on Crystalline Silicon Photovoltaics 2018

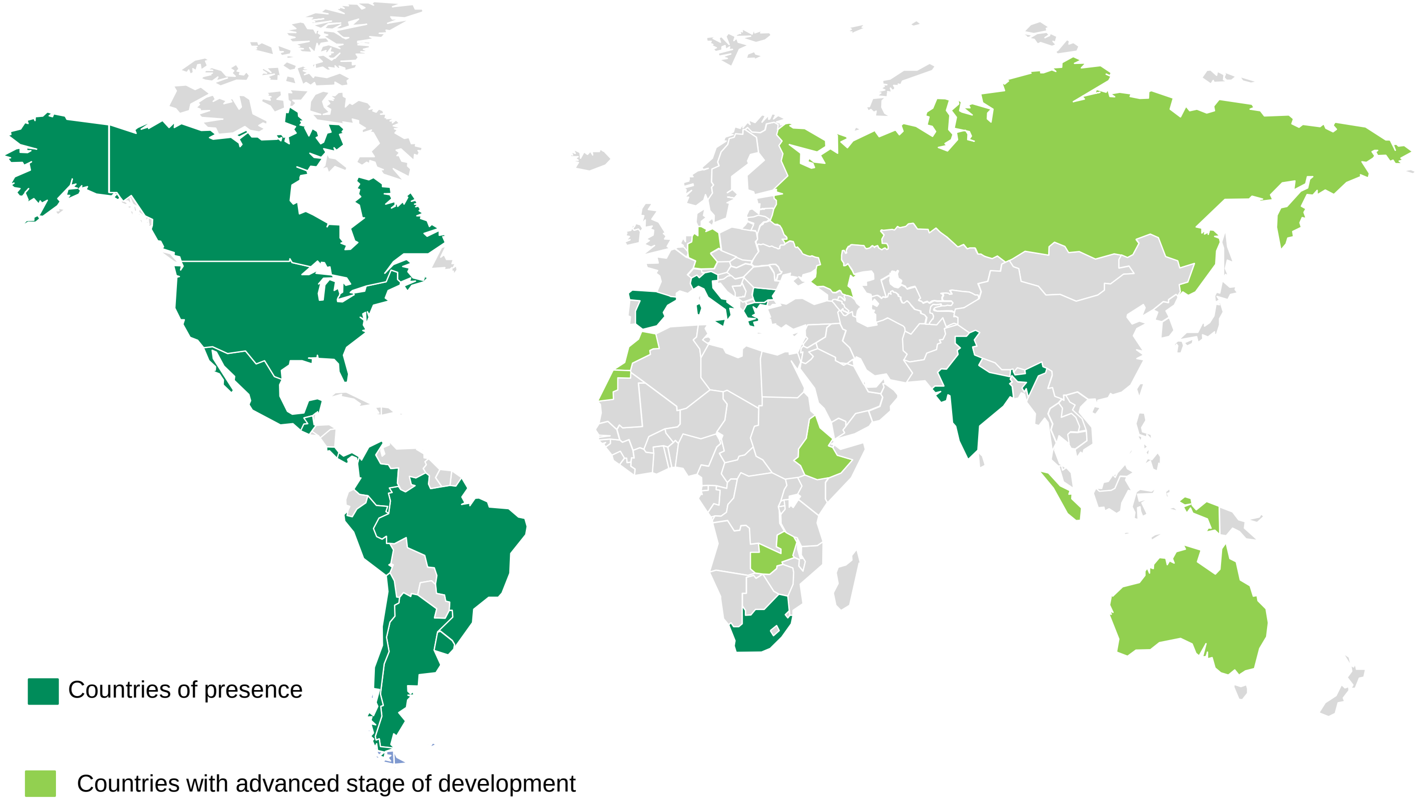
March 23rd 2018

Introduction

- Enel Green Power
- Market and Technology Overview
- LCOE Challenges

Enel Green Power

Global Footprint



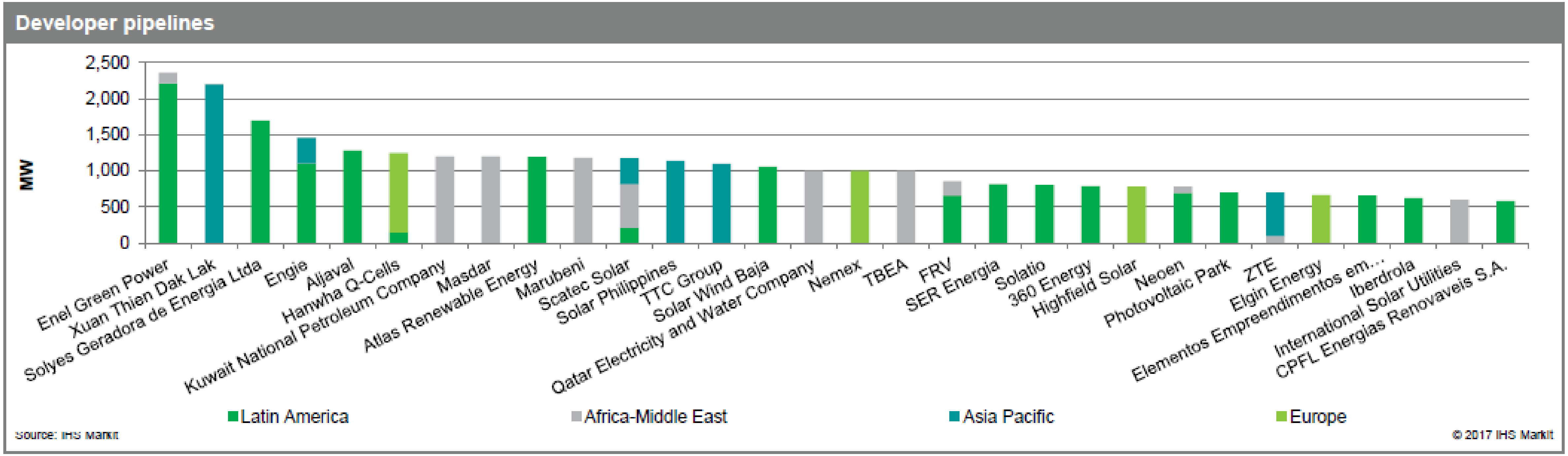
	Wind	Solar	Hydro	Geo
Consolidated capacity (GW)	6.6	2.2	27.5	0.8
Managed capacity (GW)	2.6	0.4	0.3	0.1

Key figures	2017	Managed
Capacity (GW)	37.1	40.5
Production (TWh)	85.1	92

Key financials (€bn)	2017
EBITDA	4.1
Opex	1.4
Maintenance capex	0.3
Growth capex	3.4

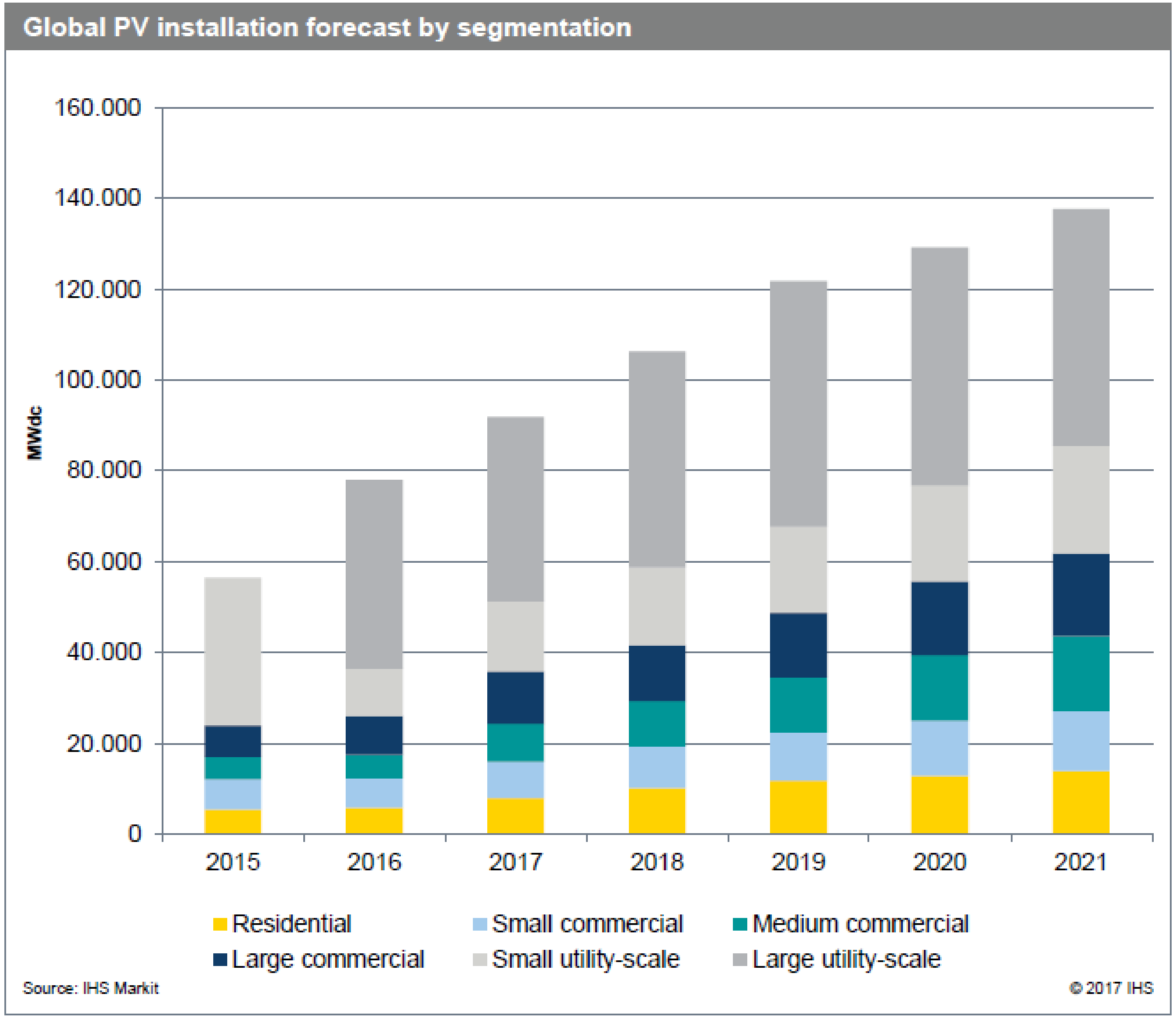
Geo Hydro Wind Solar

Developer Pipelines



Enel Green Power has reached the first position with about 2,3 GW in the pipelilne
Succeeded in several tenders (Brazil, Mexico,Peru) has started construction for all the awarded projects.

Grid-connected Forecast by System Type

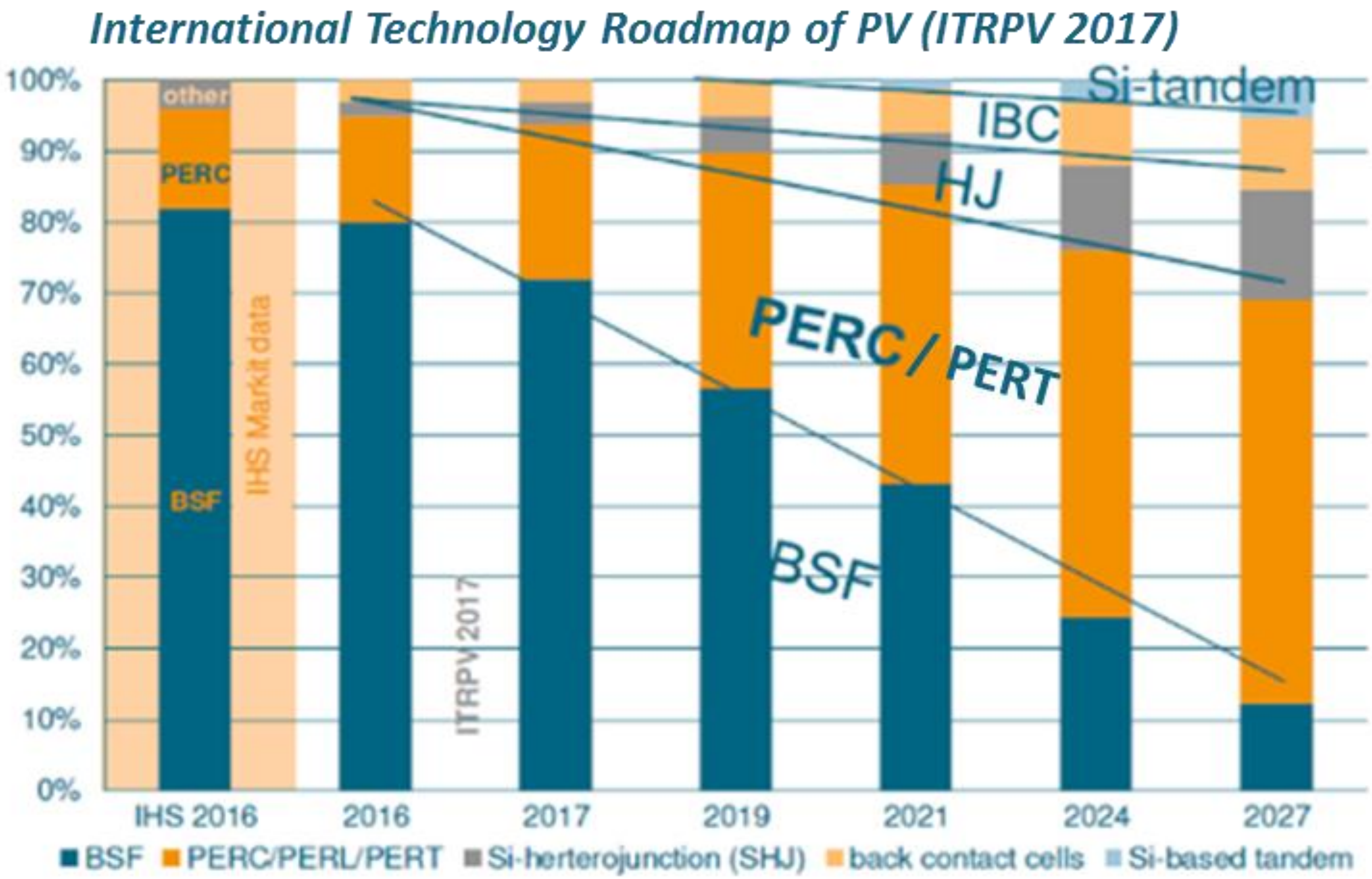


Split of the utility-scale segment from 2016 into small utility-scale (5–20 MW) and large utility-scale (> 20 MW)

- Large utility scale in 2017 44% of global demand→ fall to 37% in 2021.
- The small-and medium-sized commercial segments will benefit from more rooftop installations (India)
- Residential installations are projected to grow to reach 14 GW in 2021,

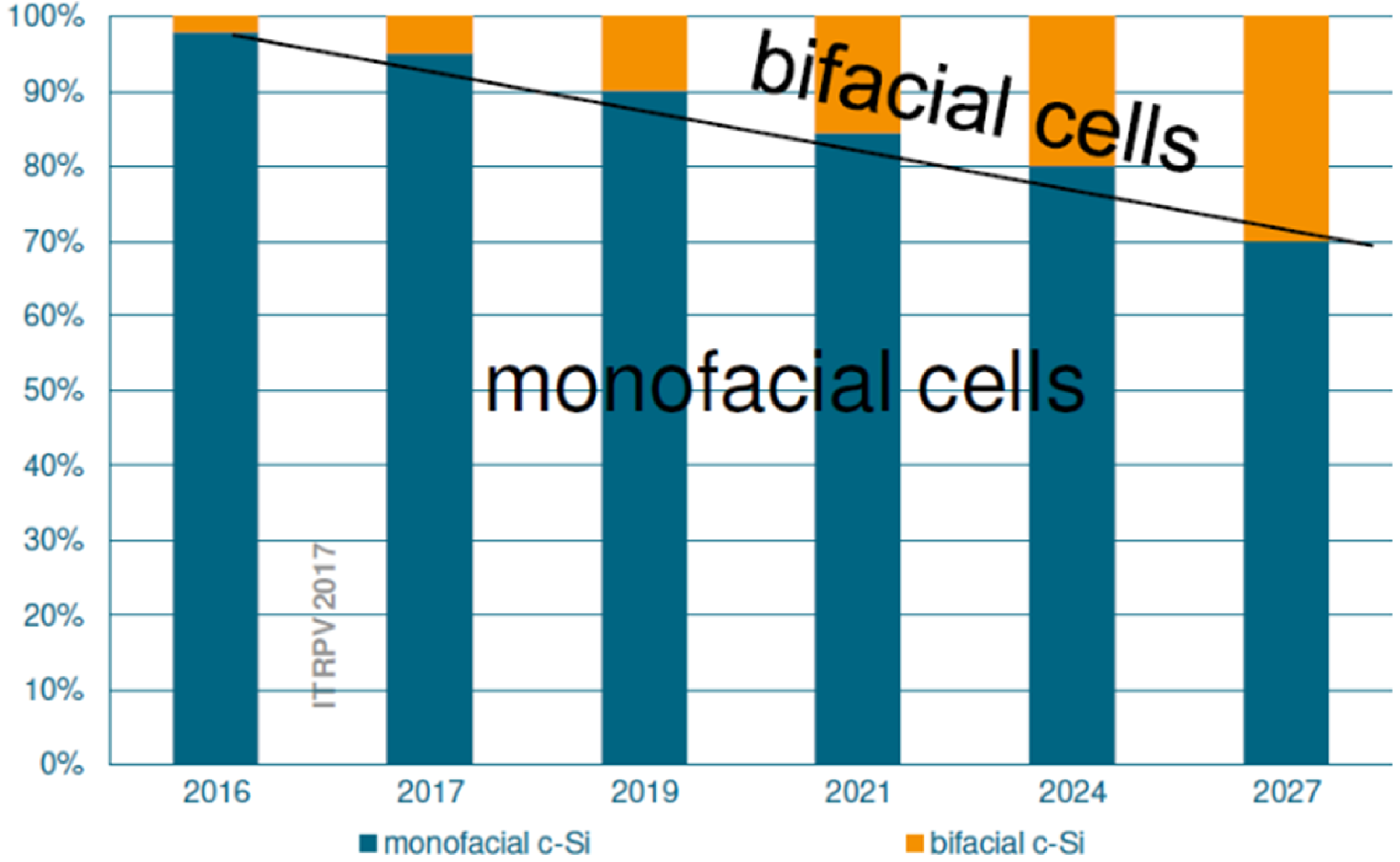
Technology Trends

High efficiency cell technologies will replace conventional BSF cells

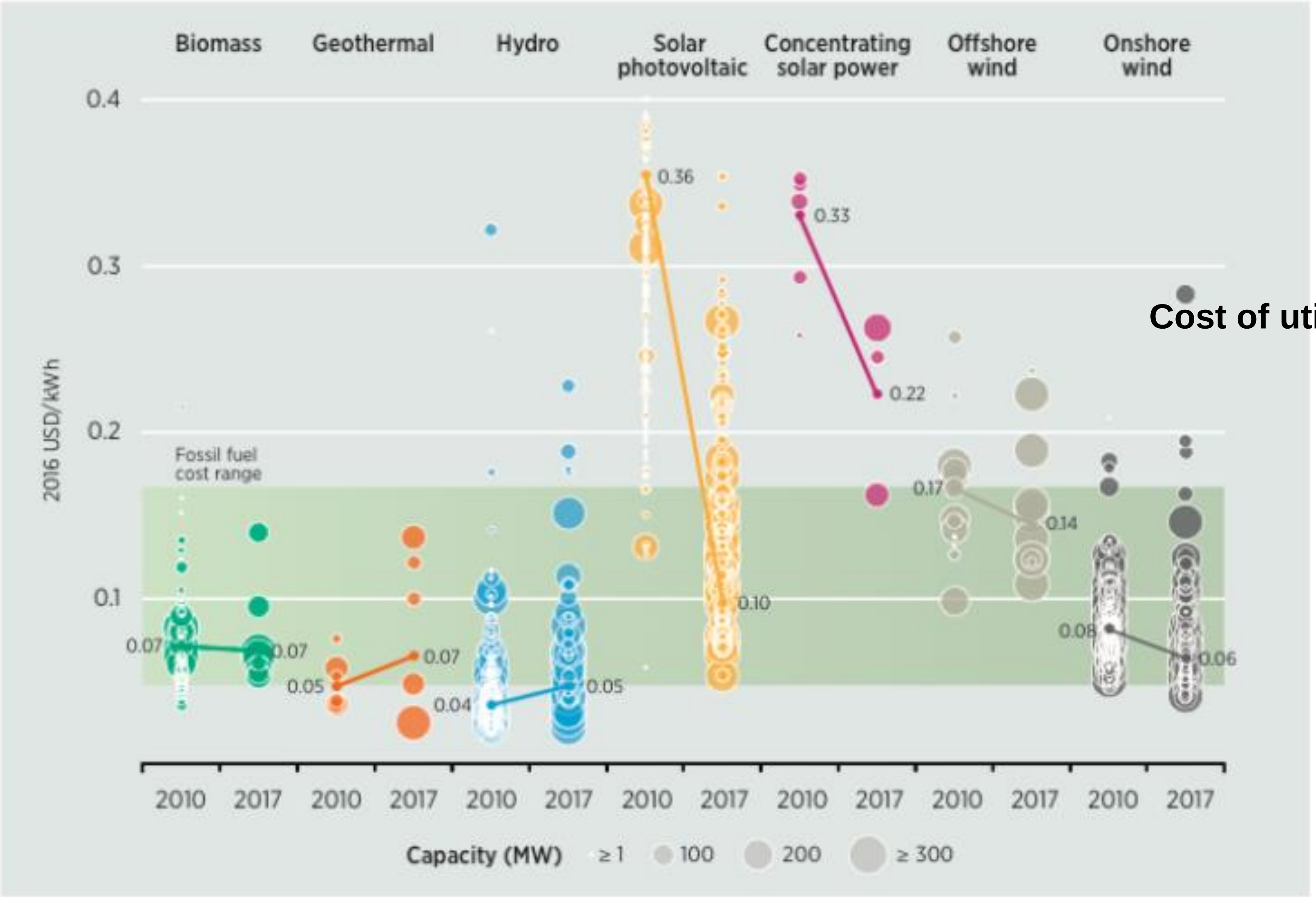


Technology Trends: Bifacial Cells

Increasing bifacial market share: +10% in 2019, +20% in 2024, +30% by 2027 (ITRPV 2017)



LCOE Form Renewable Power Generation Technologies



Source: IRENA Renewable Cost Database.

Cost of utility-scale solar huge drop in 2017.

Touched 3 $ct/kWh in 2018

New Business Model for 3SUN_ENEL Green Power

Green Power

Higher margins possible at the system level for electricity companies in many regions

3SUN

- ➢ Within this model thin film technology had problems of competitiveness
  - ➢ mc-Si is advantaged by higher efficiency, higher materials standardization and economy of scale

Strategy EGP: integrate the full value chain:

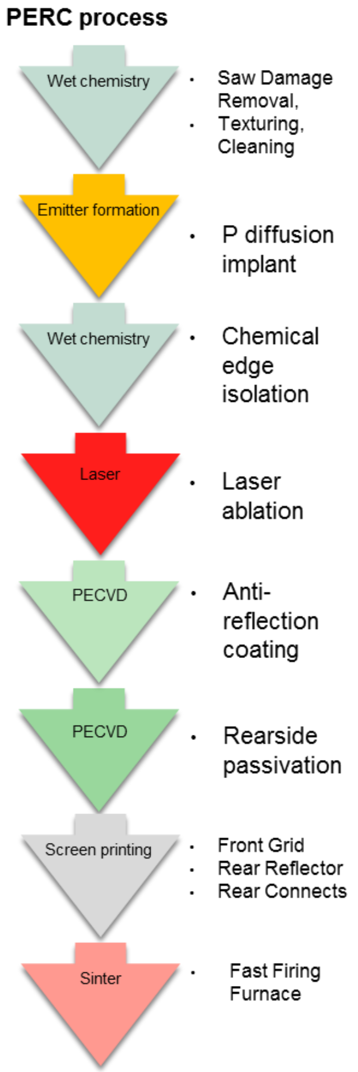
- To convert the a-Si technology to innovative wafer based technology
- Achieving higher energy production in solar plants
- To take advantage from economy of scale and standardization (of materials)

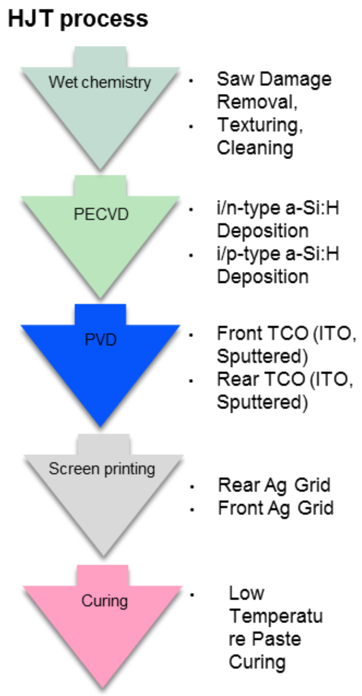
Silicon Hetero_Junction Cells:

- Why
- Material Challenges
- Efficiency Roadmaps
- Manufacturing Challengrs

HJT a simplified process flow

Green Power





Silicon based Hetero-Junction Technology (HJT)

Reduced number of process steps compared to other high performance standard technologies (Al BSF, PERC, PERT)

➔ Lower Cost of Ownership

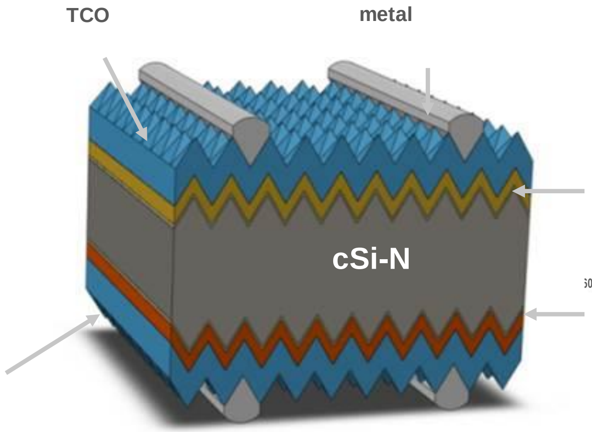
High T processes 800°C

Low T processes 180 – 200°C

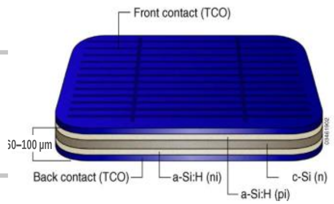
Eff = 19-20.5% **Eff = 21.5 - 22%** **efficiency in production**

Si-HJT Cell : An Innovative Technology for Utility Scale

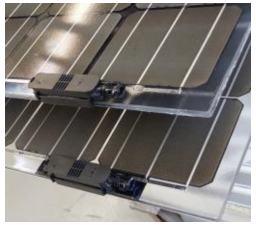
- ✓ **High efficiency potential with outstanding V_{oc}**
  - ✓ up to 750 mV and > 25 % demonstrated
  - ✓ 22 % in production
- ✓ **Lifetime:**
  - ✓ Very low PID thanks to TCO and glass-glass
  - ✓ 40 years (vs 30 years)
- ✓ **Energy Yield higher than standard cells due to excellent temperature characteristics**
  - ✓ -0.25 %/° C compared to -0.35%/° C
  - ✓ No LID
  - ✓ Bifacial modules possible (+10-20% energy yield)
- ✓ **Large area deposition potential, high throughput**
- ✓ **Low Temperature process**
  - ✓ No bulk carrier lifetime issues during process .
  - ✓ Compatible with thinner wafers
- ✓ **Reduced number of process steps**
  - ✓ Lower Cost of Ownership



HJT Cell bifacial

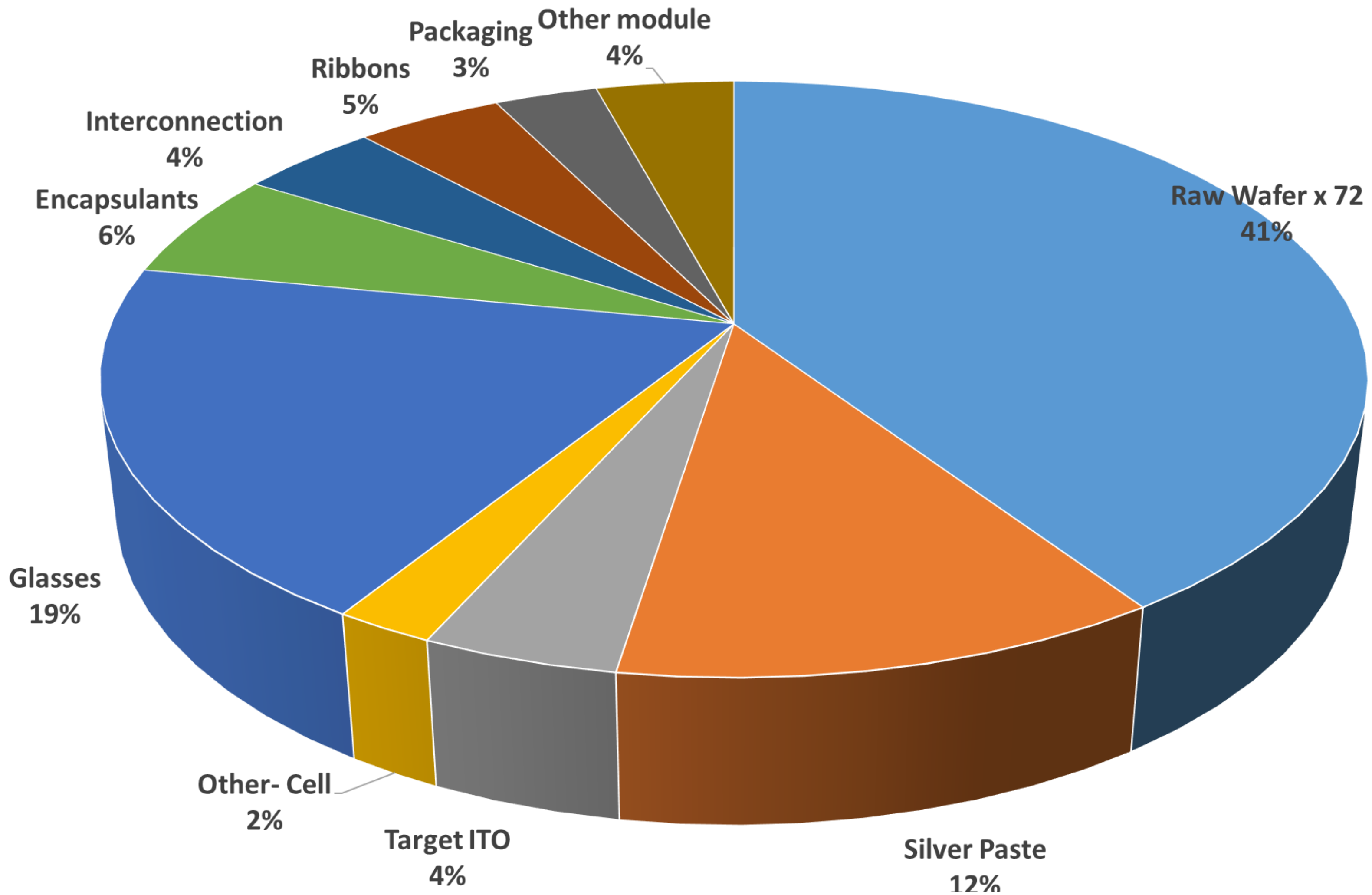


Bifacial glass glass module



- **Easy and symmetric process that allows to produce** bifacial cells → more energy
- **Combine the advantages of c-Si (high efficiency) and the advantages of amorphous silicon (low degradation with temperature)** → more energy
- In the "utility scale" application HJT allows to obtain an energy cost lower than all the other technologies

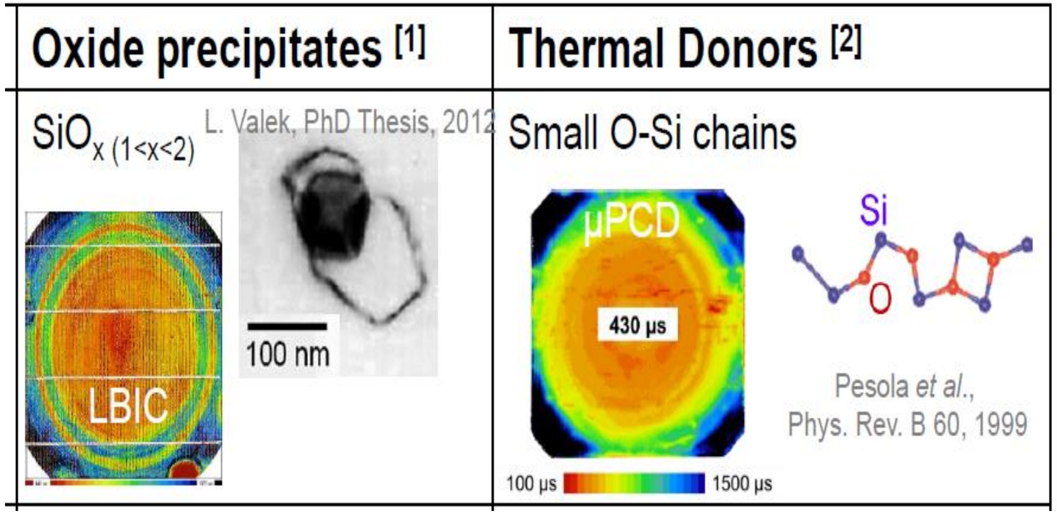
Si HJT Cell and Module Manufacturing: Material Challenges

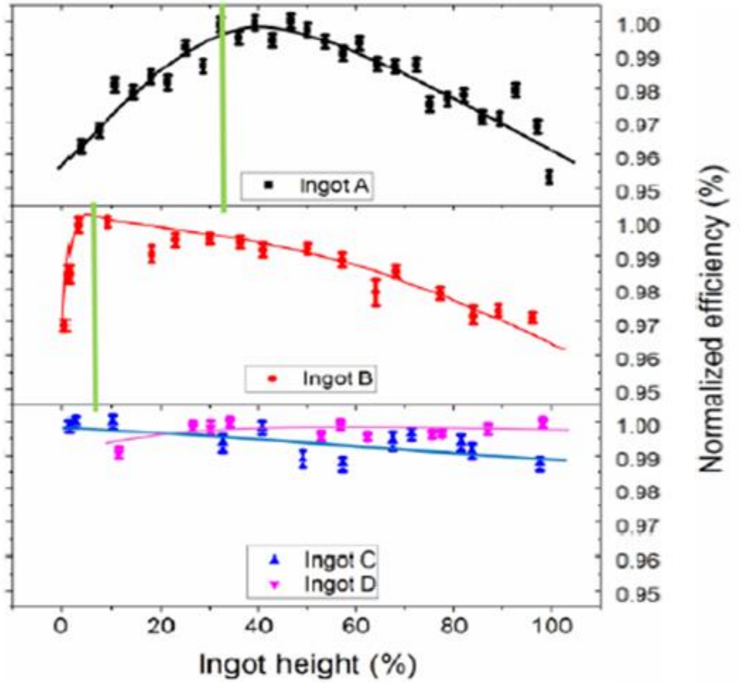


Critical trade off between costs and efficiency driven by:

- **Wafers**
- **Metallization**

Wafer Challenge: The incoming quality





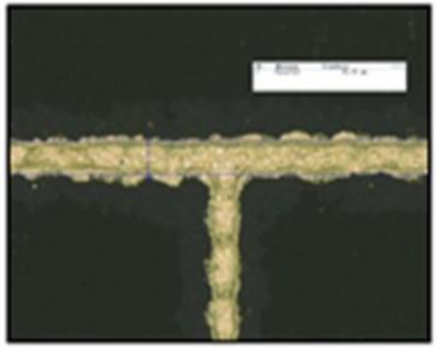
- Various defects can affect ingot bulk quality (Oxygen, metallic, etc.),
- Thermal donor and O related defects can affect the resistivity and lifetime in Cz silicon. Their influence depends mainly on thermal history during the ingot growth (seed side is more prone to TD and O precipitates),
- Serious improvements have been made in the last years to reduce impurities concentrations and distribution along ingot.
- Still room of improvement in ingot quality production

[3] E. Letty, PhD thesis 2017
[4] J. Veirman et al., Review of n-type materials for silicon solar cells, npvvorkshop 2018

Ag Metallization: Bus Bar Challenges

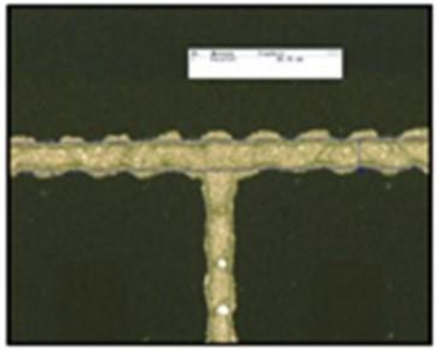
Green Power

- **Ag paste selection has strong impact on efficiency and costs**
  - Line resistance (RL< 1Ω) and a rheology → high aspect ratios.
  - Material compatibility with module assembly processes (ribbons, ECA)
  - HJT Ag paste curing at low temperatures
  - Limited number of suppliers at right maturity level



More uniform

- **Cell layout design optimization is crucial:**
  - Ag paste mg/cell reduction
  - Optimization of layout for best module interconnection

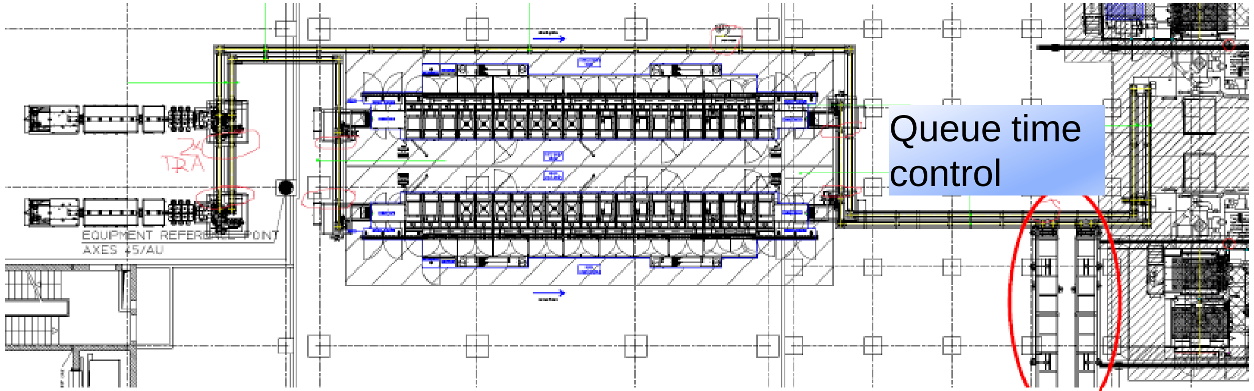


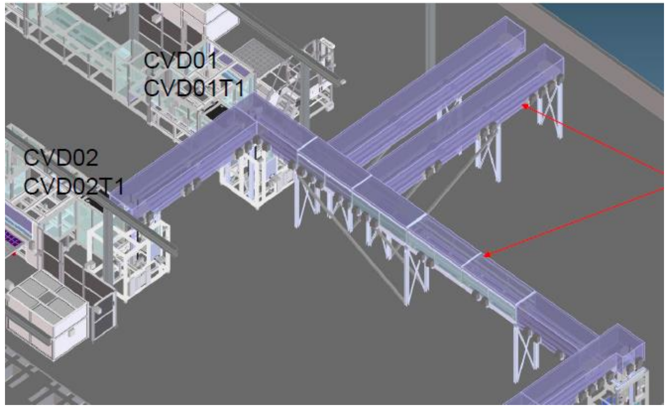
Higher spread

- **Multi-bus bar efficiency gain vs Ag paste consumption**

Manufacturing Challenge: Automation Features

Special automation design to minimize surface re-oxidation



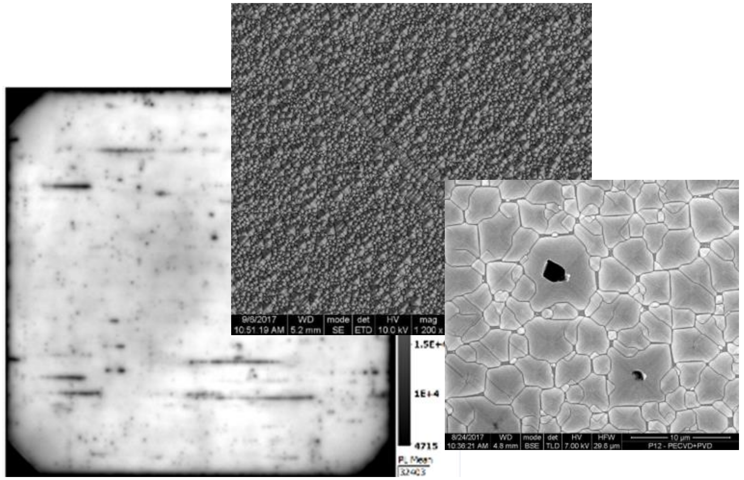


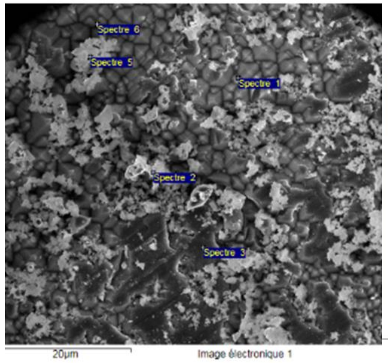
- N2 buffers if predicted queue time exceeds the limit
- Automatic routine for re-work

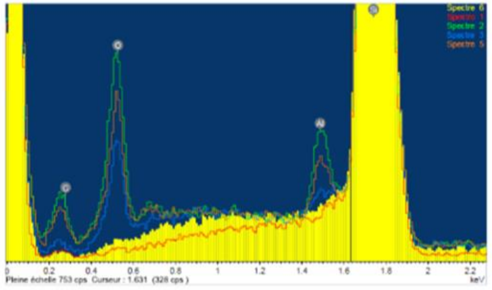
Improved transportation system before PECVD.

-Improved belt material to reduce surface damage and to limit debris accumulation

- Grips to limit organic and metal contamination







Manufacturing Challenge: Advanced Process Control

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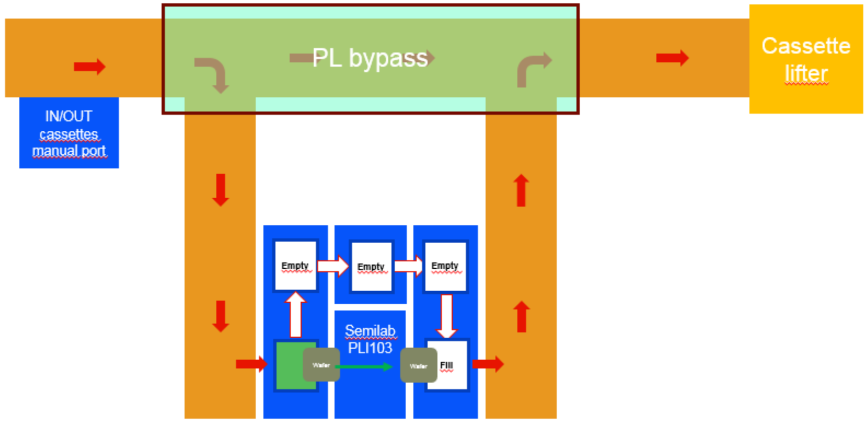
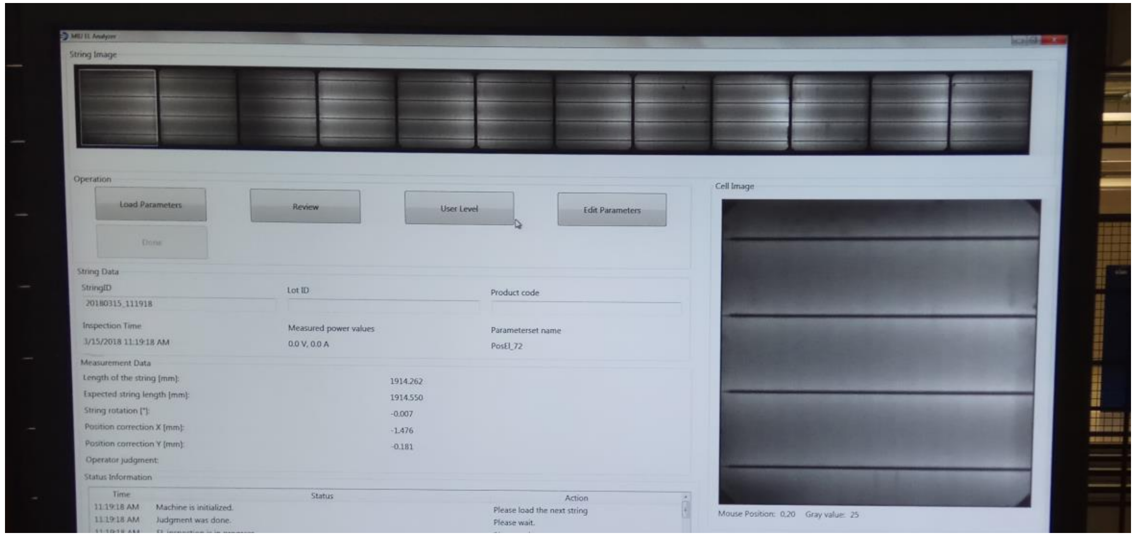
Real time, in line, process control and automatic violation detection to fasten corrective actions and improve fab efficiency.

- Tracking by Virtual wafers
- Automated PL sampling post PECVD and PVD
- Process parameters (off line measurement) control by advanced MES features
- 100 % EL measurements at cell level
- 100 % EL inspection at string level, before lamination, after lamination
- Automated visual module inspection





HJT Cell short-term development strategies

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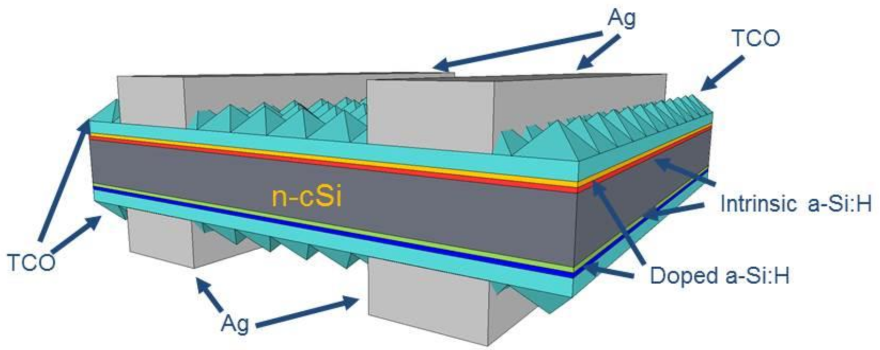
- Silicon material improvement
- Wet process control improvement
- PECVD layer engineering to ensure low recombination and higher transparency
- TCO for low damage, optimized transparency and conductivity
- Metal grid layout for reduced shadowing and efficient carrier collection
- Defectivity management
- Optimization of bifaciality,



Latest improvement already demonstrated at the HJT CEA pilot line *[6]*

Cell	Area (cm^2)	Voc (mV)	Jsc (mA/cm^2)	FF (%)	η (%)
BB4	244.3	732.4	37.5	80.0	22.0
BB6	244.3	738.3	38.6	80.6	23.0

IV parameters obtained for Si-HJT cells produced at CEA-INES under STC at Fraunhofer CalLab.

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

[6] Abstract submitted to World Conference on Photovoltaic Energy Conversion (2018)

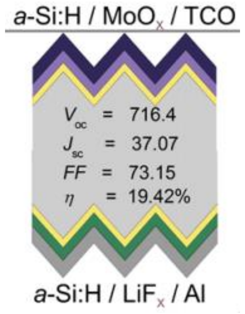
Path to higher efficiency → Beyond 25 % is possible

Development strategies:

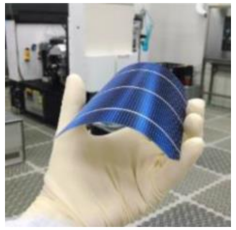
- New thin layers for junction/passivation engineering
- Advanced TCO materials and deposition methods,
- Half cells
- Use of Cu for metal grid
- Thinner cells

Main drivers:

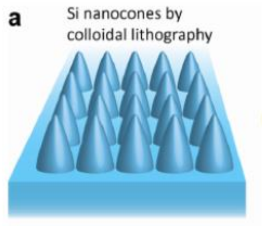
- Reducing silicon and metallization costs
- Increasing energy generation
  - a) bifacial cells
  - b) light harvesting with plasmonics and nanotechnologies



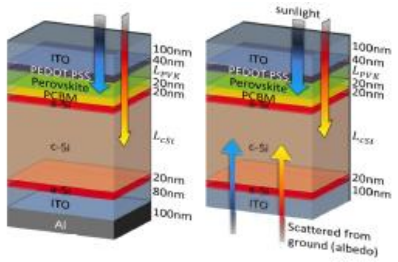
Selective Contacts



120um → 80um → 40um



Light trapping Plasmonic



Perovskite/c-Si tandem

Bifacial tandem

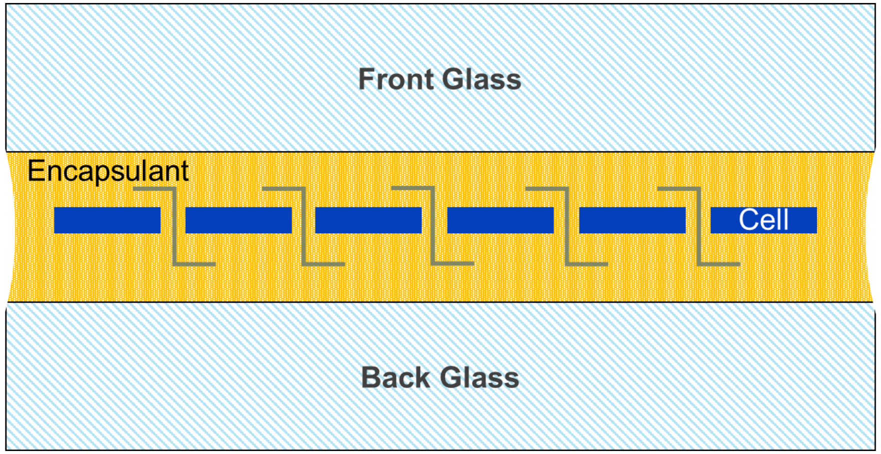
Tandem

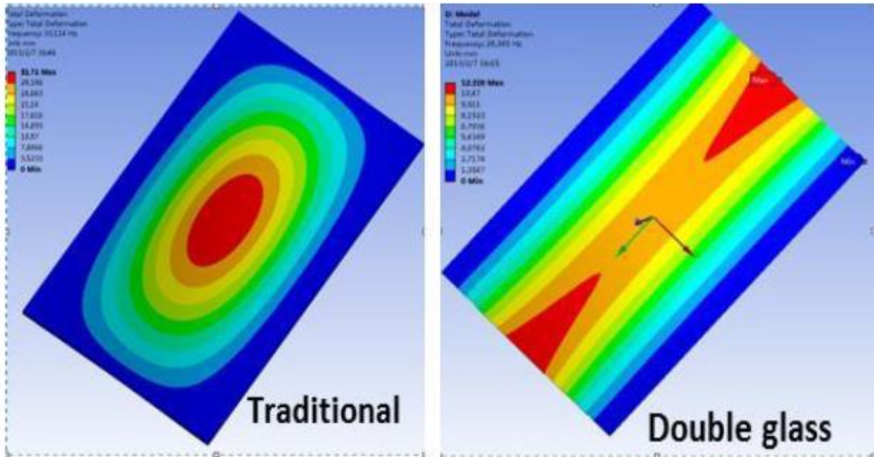
Due to the low T process HJT can take advantage from many technology upsides

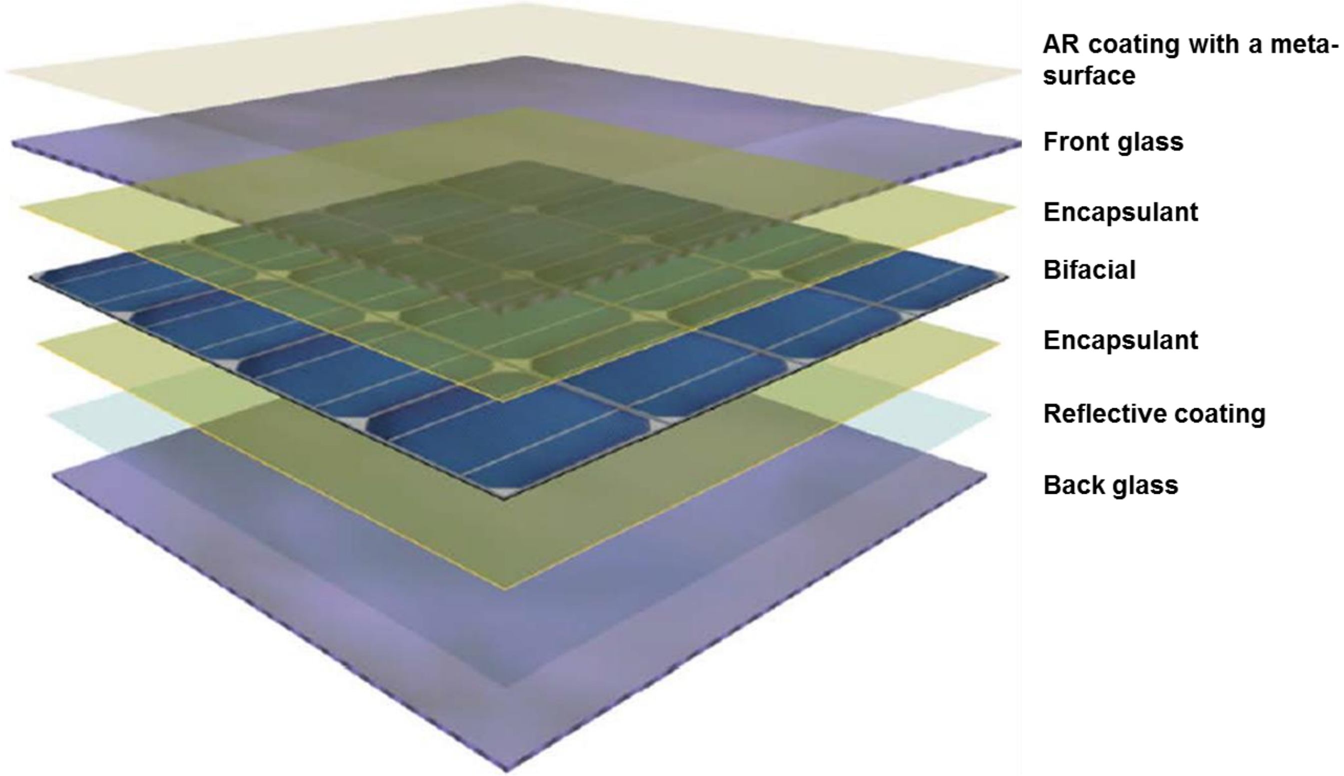
Bifacial HJT Modules

- Focus on Reliability
- Focus on Bifacial gain

Increased reliability with glass - glass



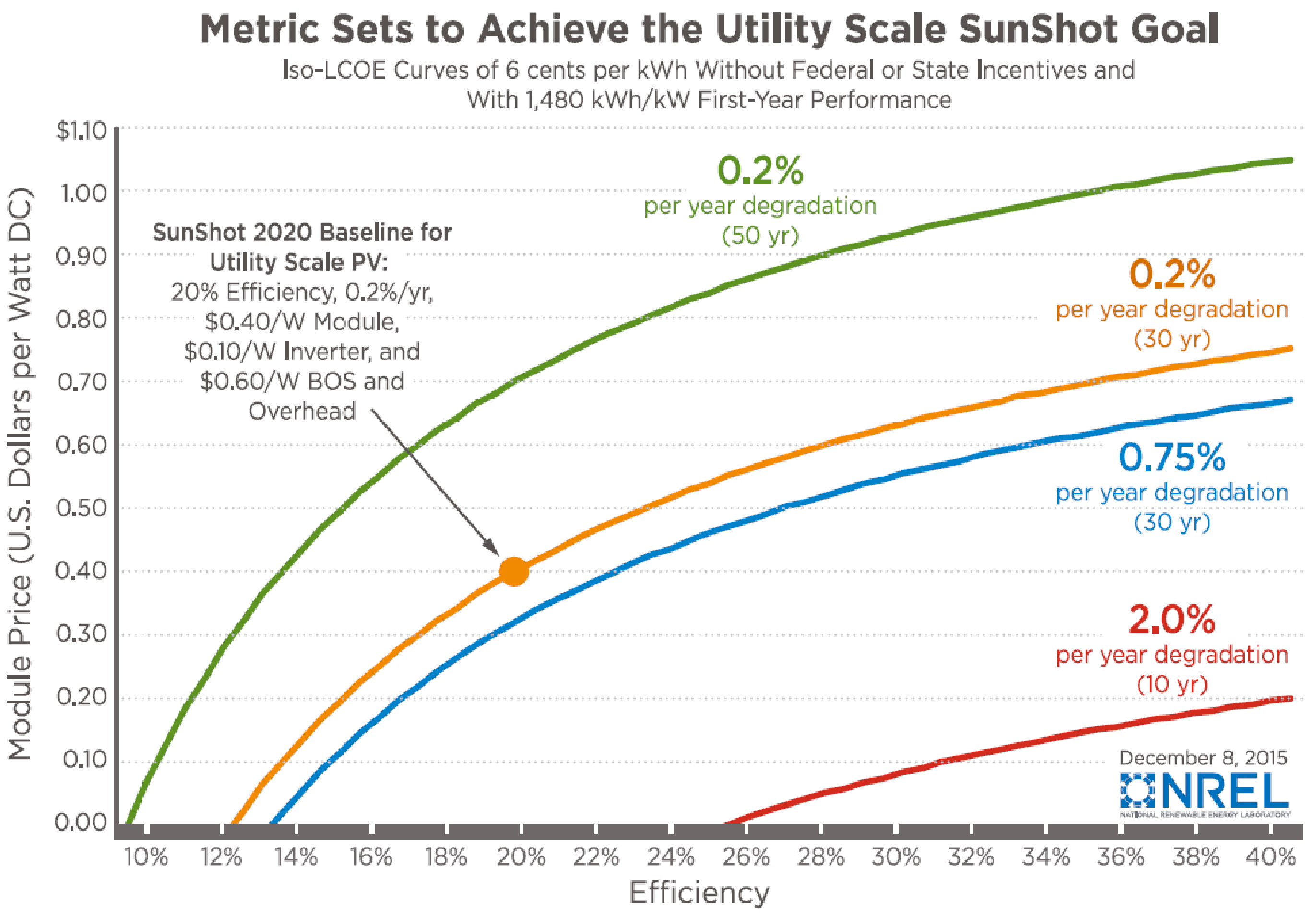




- Reduction of potential induced defects (PID)
- Increased robustness against moisture and UV degradation
- Durability 35 – 40+ years
- Mechanical robustness

Cost-Performance Trade-offs

Reliability impact

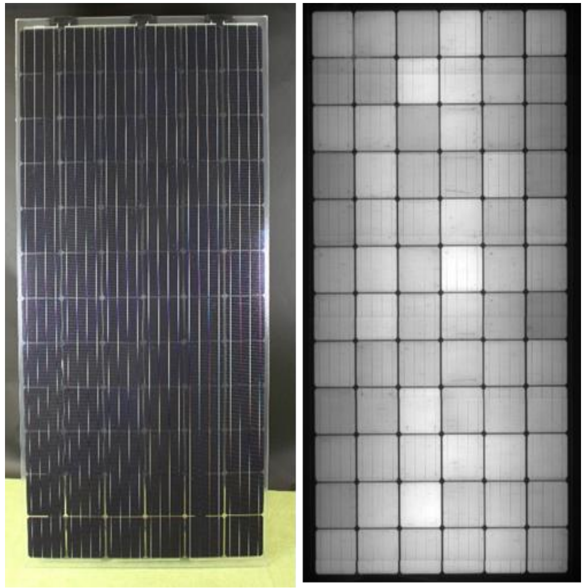


- Modules with lifetimes ≤ 10 years and high degradation rates cannot achieve competitive LCOE unless they are simultaneously very low cost and very high efficiency.

Rebecca Jones-Albertus et al. “Technology advances needed for photovoltaics to achieve widespread grid price parity,” Prog. in Photovolt: Res. Appl. (2016)

HJT: 72 Cells Bifacial Modules

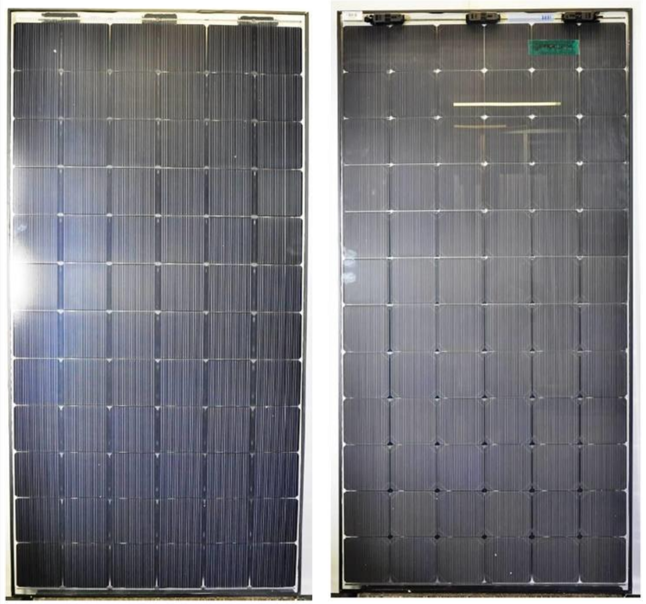
72 HJT cell module, Bus-Bar



Side	P_{max} (W_c)	V_{oc} (V)	I_{sc} (A)	FF (%)
Front side	380.7	53.4	9.15	77.9
Back side	331.5	53.3	7.95	78.2

72 HJT cell module, Smart Wire In Free

MEYER BURGER



	P_{max} [W]	V_{mpp} [V]	I_{mpp} [A]	V_{oc} [V]	I_{sc} [A]	FF [%]
front	380.5	43.9	8.7	52.8	9.1	79.0

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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 Horizon2020 Programme for research, technological development and demonstration under Grant Agreement N° 745601.

HJT Bifacial Modules Outdoor Monitoring

Focus on performance

Two outdoor monitoring systems are installed to explore different environmental conditions and focus on bifacial gain and HJT performances.

Modules Benchmark
Monofacial p-type pc-Si
Bifacial n-PERC
3SUN BB HJT initial generation 72 cells
MB SWCT HJT bifacial 60 -72 cells
3SUN HJT BB final generation 72 cells
3SUN HJT final generation with backsheet 72 cells
Commercial Premium HJT bifacial 72 cells

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Focus on system components

(1) Totana – Murcia -Spain

(2) Valdecaballeros – Badajoz - Spain

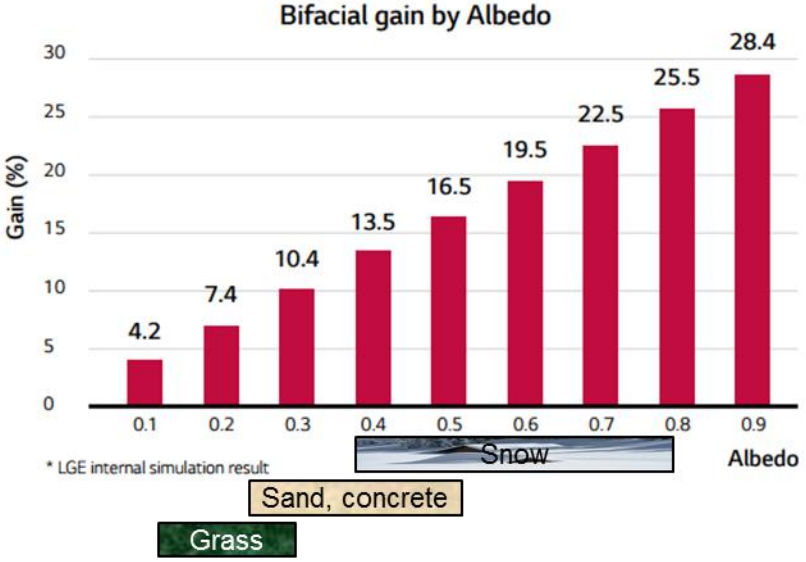
(3) Logrosan- Caceres- Spain

(4) Guillena – Sevilla - Spain

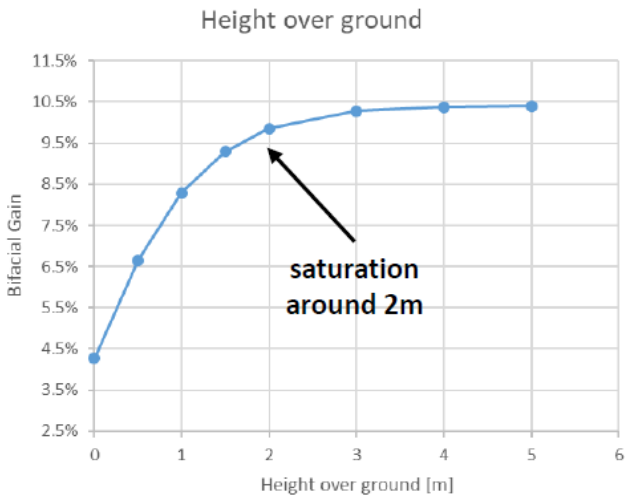
- 500 kW (4x125 kW sectors) integrated pilot system to be installed inside an EGP operational PV plant in Spain
- 4 different system configurations of the same power for the parametric study and cross analysis at the PV components

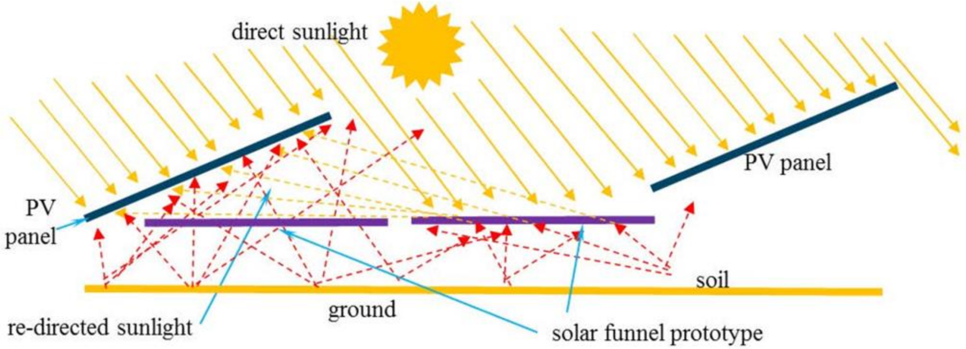
This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 792059*

Bifaciality : System level optimization



- Comparison of tracker mounting systems (single-axis) vs fixed structures
- Installation at different height from the ground
- Ground covered ratio (module area/ground area; pitch vs bifacial gain studies
- Natural Albedo vs artificial albedo





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