Si HJT bifacial modules an innovative industrial perspective towards more efficient PV energy generation

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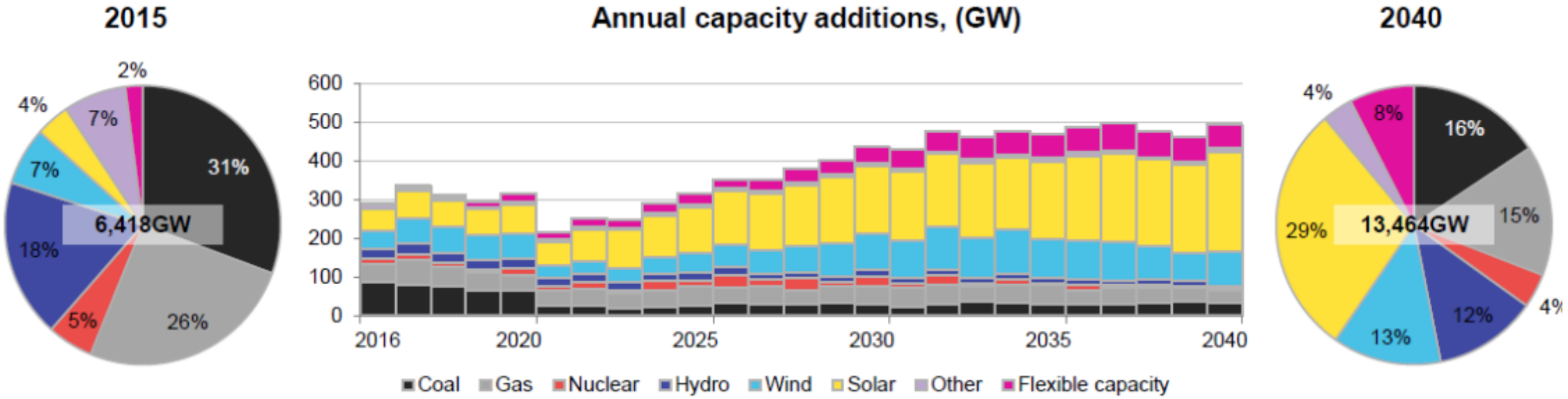
The PV Market:
- overview
- strategic competitiveness

Global Energy Market Overview

Global installed capacity in 2015 and 2040 and capacity additions, 2016-40



Source: BNFE New Energy Outlook 2016

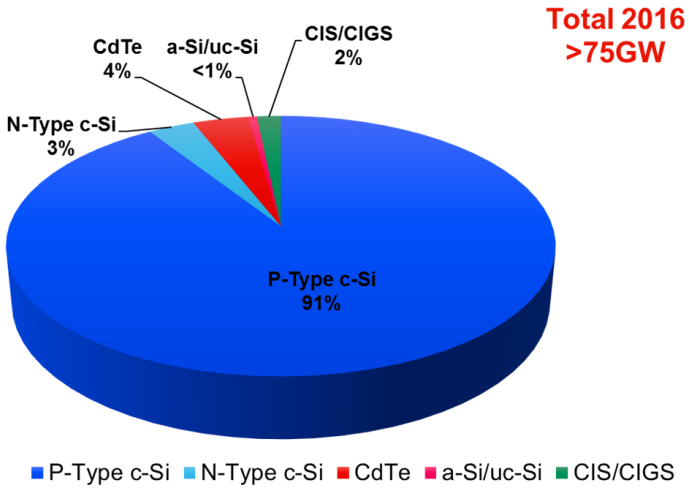
The role of PV will be increasingly important in the global energy production scenario.
It is forecast that in 2040 PV will achieve a market share of ~ 30%.

PV Market Overview
Global PV Market

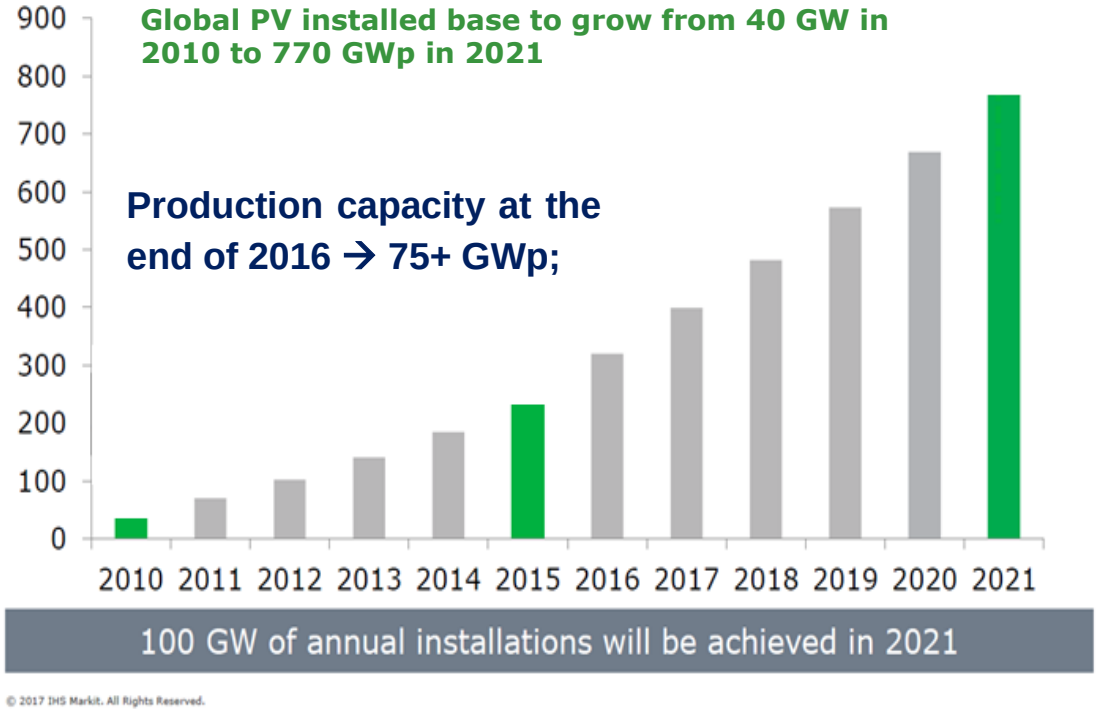
The PV market is driven by LCOE* reduction.

Cell and module cost decrease mainly related to:

- products efficiency enhancement - more power generated by panels
- more efficient value chain and scale economy



Total 2016 >75GW



Crystalline PV dominate the market: 94% of shipments in 2016

Source IHS_2017

(*) LCOE Levelized Cost of Energy

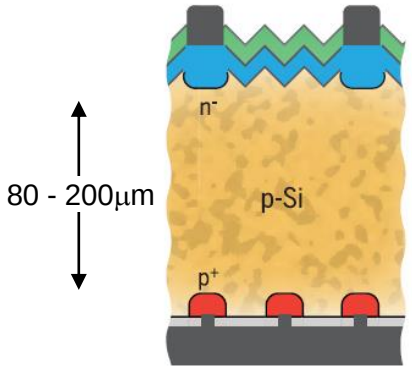
PV Technology:
-state of the art
-technology competitiveness

Solar Cells Architectures

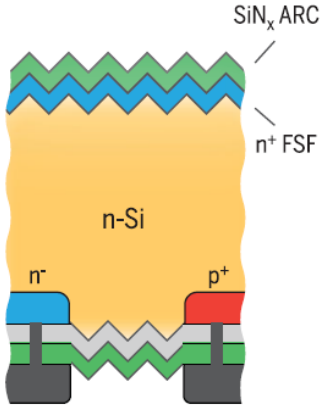
State of the art and new developments

Si Wafers
Higher stabilized Efficiency
Eff:18 – 25%

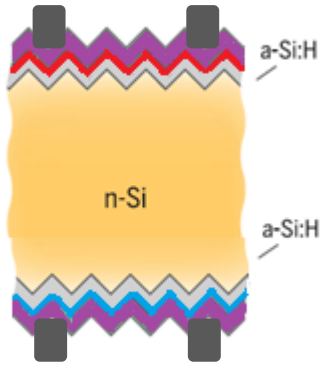
mc-SI (PERC)



c-SI (IBC)

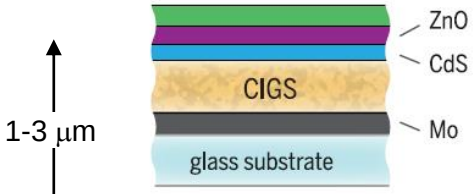


Si –(HJT)



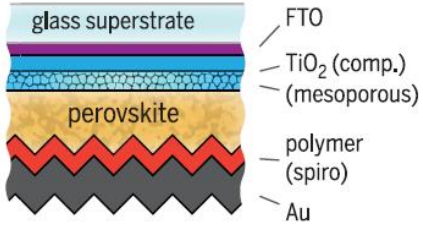
Thin Film
Lower stabilized Efficiency
Eff: 11 – 20%

CIGS



CdTe

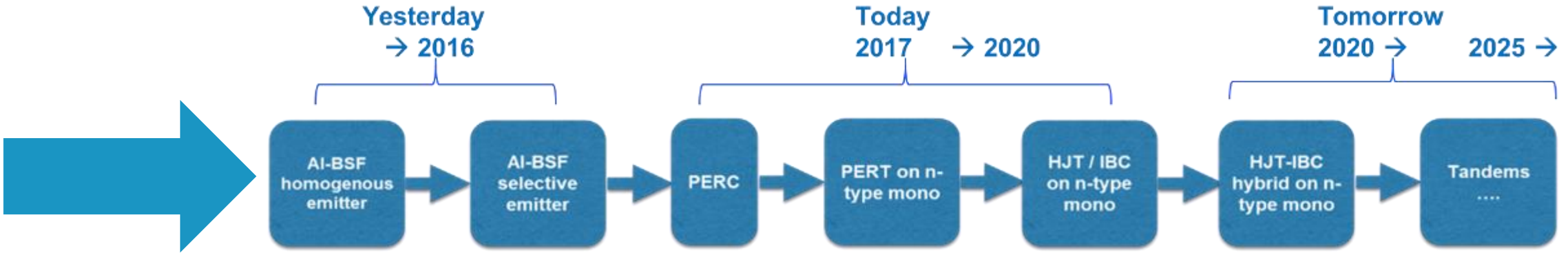
Perovskite



absorber | n-type / e⁻ contact | p-type / h⁺ contact | ARC | TCL | metal | passivation / window

Technology Competitiveness

Si Solar cells Current Status and Development



	poly-Si (Al-BSF)	PERC p-type	PERT n-type	HJT	IBC	Tandem cells
Min wafer thickness	180 µm	180 µm	180 µm	80 µm	100 µm	-
Cell Efficiency	17% → 19%	20% → 22%	21% → 23%	22% → 25%	22.5% → 26% →	25 – 30%
Energy generation Thermal coefficient	-	-	-	+10%	+5% IBC +10% IBC HJT	under study
Energy generation Bifacial	-	+10%	+15%	+25%	-	under study
Reliability / Lifetime	Low: PID + LID 0.5%/year	Low: PID + LID 0.5%/year	Medium: PID, no LID 0.3%/y	High: no PID no LID 0.25%/y	High: no PID no LID 0.25%/y	under study
Costs/Wp	Low	Low	Medium high	Medium	High	under study
Costs/kWh	Medium low	Medium low	Medium	Low	Medium high	under study
Competitiveness	**Obsolete technology Limited effic roadmap**	**Incremental vs mc-Si Low eff increase**	**Incremental vs PERC Medium eff increase**	**Disruptive High eff increase**	**Disruptive High eff increase**	**Long term Very high effic**

The 3SUN company

-the factory
-the new strategy : “3SUN 2.0” Program
-the innovative Si HJT bifacial modules

3SUN

3SUN is a photovoltaic modules' factory based on multi-junction a-Si technology, located in Catania (Italy), owned by Enel Green Power

The biggest PV Italian fab and one of the most important in Europe

Actual Core Process: amorphous + µ-cristalline silicon deposition

- Two production lines working in parallel
- 8 PECVD clusters per line
- Total 96 deposition chambers with 8 slots per each
- Deposition process rate is 2 panels every 43 seconds
- ~4.000 PV Modules/day as annual average

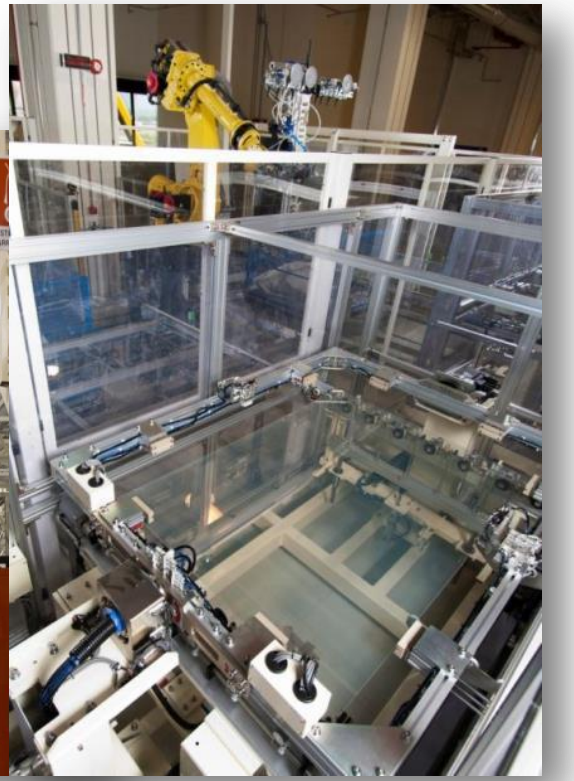
The Plant size:

- 240.000 m^2 surface area
- 115.000 m^2 of usable surface
- 50.000 m^2 Fab area
- 3 floors of 16.000 m^2 each
- 300+ permanent employees
- 200 MW/year production capacity
- About 7 millions of modules produced since Dec 2011

Efficient and Fully Automated Production Lines

3SUN enel Green Power

10hrs from Glass input to Pallet Output



International expansion with products manufactured by 3SUN

… just few examples!

Altomonte (Italy)

Istia (Italy)

Brazil

South Africa

Chile

PV Market Trends and Strategies

New Business Model for 3SUN

- Reducing the cost of energy
- €/Wp → €/kWh

- Thin film technology has problems of competitiveness
- mc-Si is advantaged by higher efficiency, higher materials standardization and economy of scale

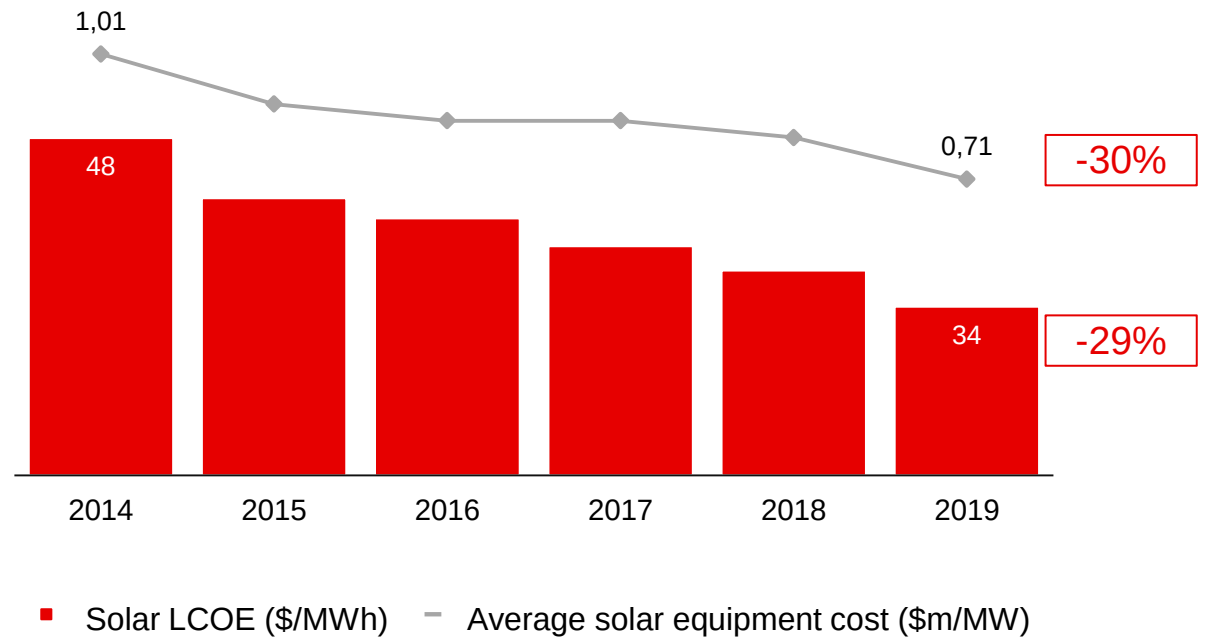
Strategy of 3SUN integrated within the EGP value chain:

- 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

Evolution of the solar technology

Solar equipment versus cost of energy

Solar equipment cost[2] by delivery date & LCOE[1] evolution



How can the European solar industry compete in such a context?

Europe can regain leadership if it can **change the current paradigm**:

from "**reduce cost of modules**" (€/Wp)

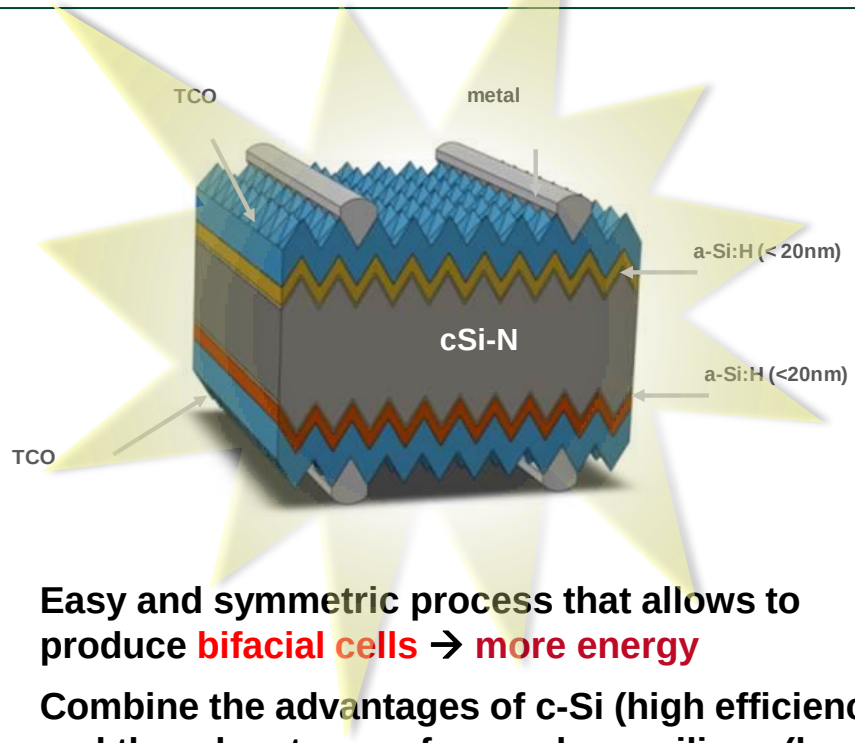
to "**reduce cost of energy**" (€/kWh) and services connected with **distributed renewable generation**

To be competitive the European solar industry needs to focus on the cost of energy

1. Normalised LCOE based on 2014 levels
2. Includes PV module, inverter, tracker, BOP, related service costs

An Innovative Technology for lowering LCOE

Silicon HJT bifacial solar cells



- **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**

High efficiency potential with outstanding V_{oc}
➔ up to 750 mV and > 25 % demonstrated

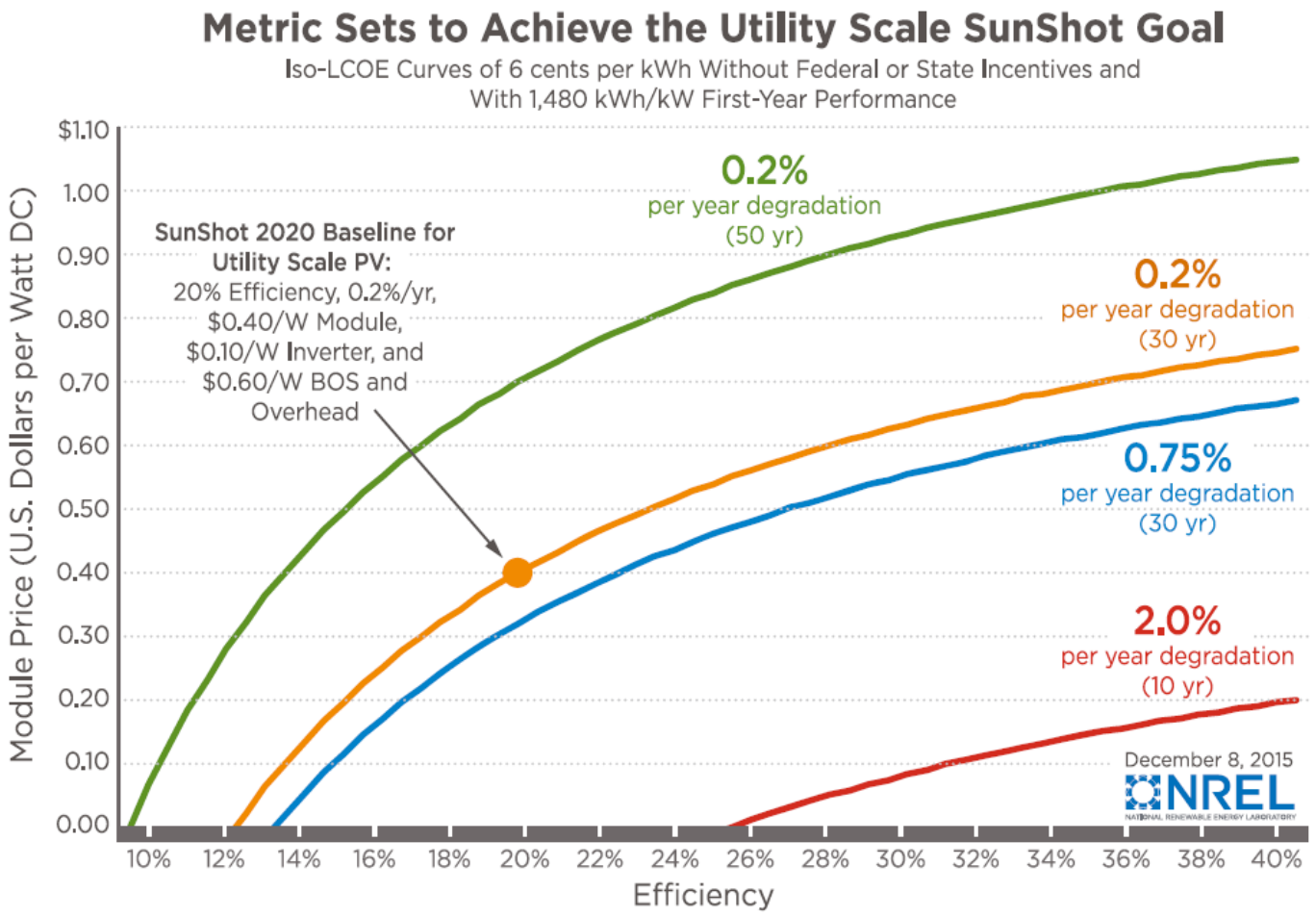
Energy Yield higher than standard cells due to excellent temperature characteristics
➔ -0.25 %/° C compared to -0.45%/° C
➔ Bifacial modules possible (+10-20% energy yield)

Low Temperature process
➔No bulk carrier lifetime issues during process .
➔Compatible with thinner wafers

Reduced number of process steps compared to other high performance standard technologies (PERC, PERT)
➔ **Lower Cost of Ownership**

Cost-Performance Trade-offs

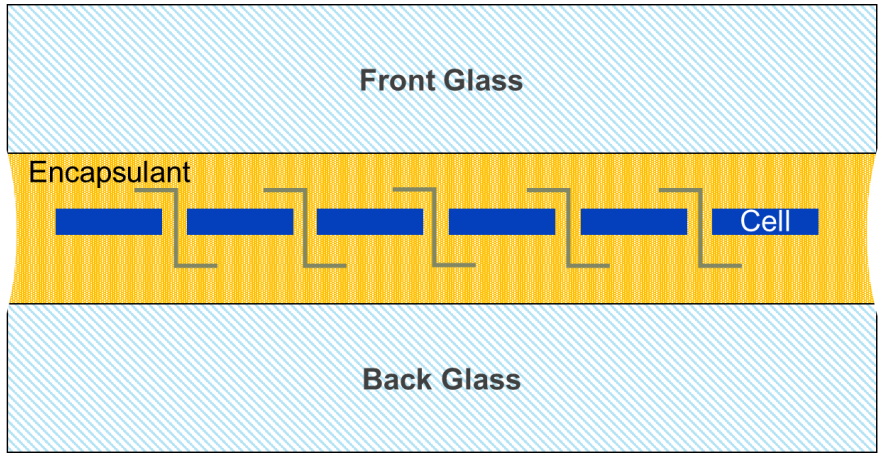
Reliability impact

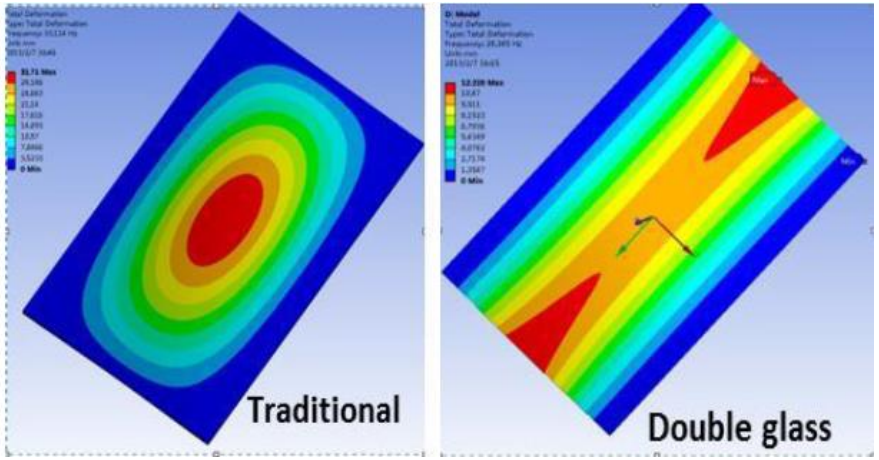


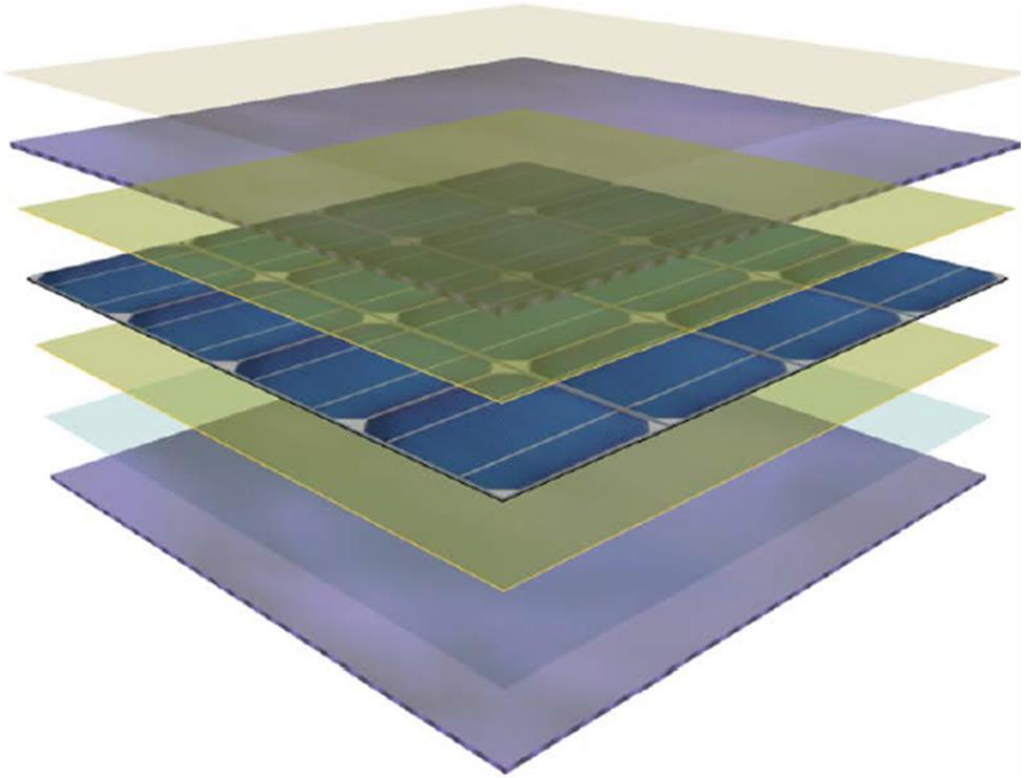
- Modules with lifetimes ≤ 10 years and high degradation rates cannot achieve competitive LCOE unless they are simultaneously very low cost and very high efficiency.

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

Increased reliability with glass - glass

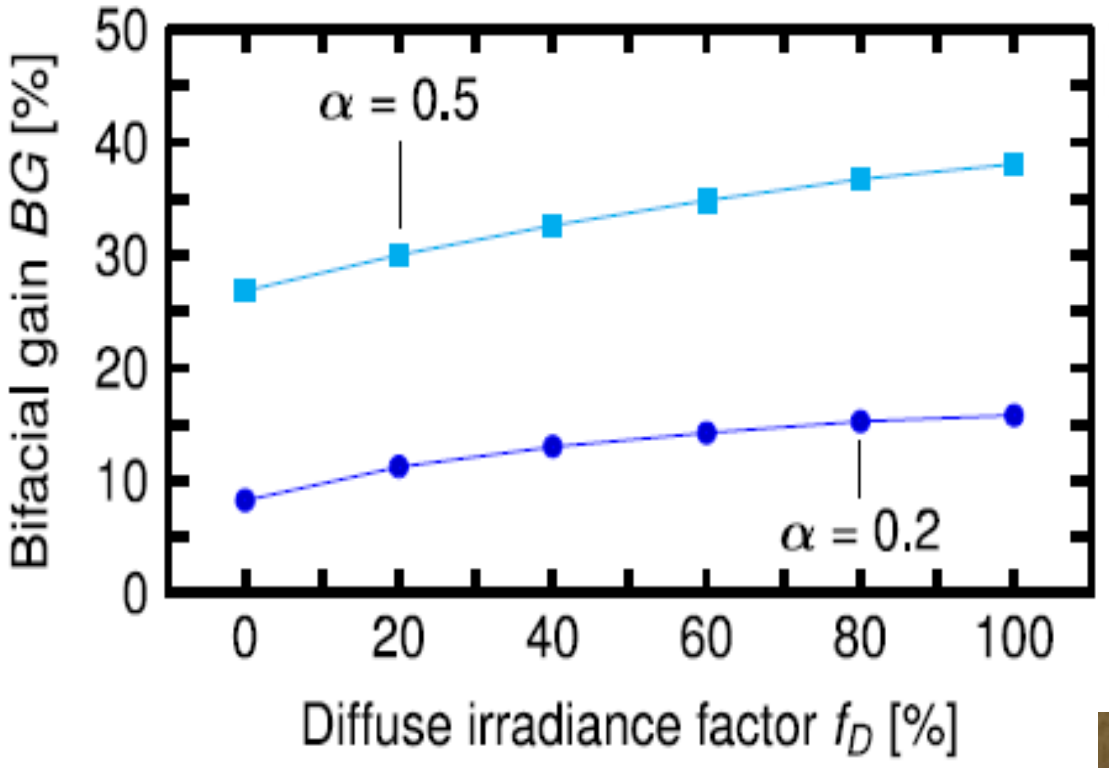


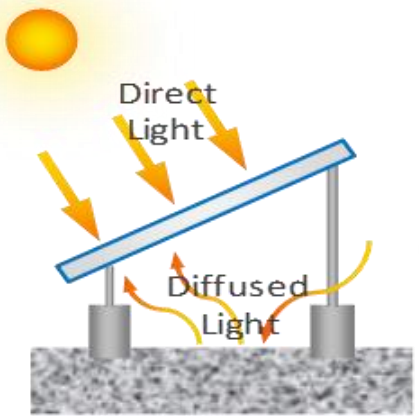


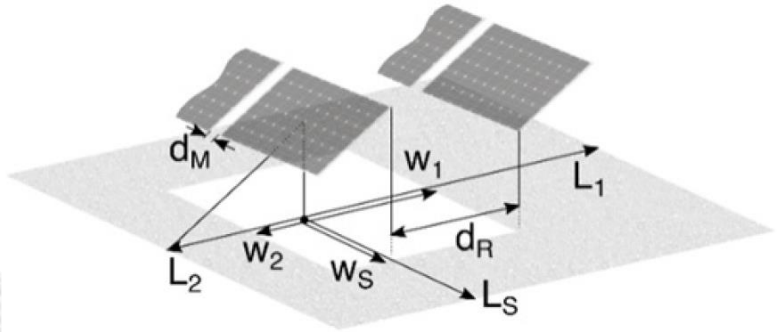


- Reduction of potential induced defects (PID)
- Increased robustness against moisture and UV degradation
- Durability 35 – 40+ years
- Mechanical robustness

Bifacial → Energy gain







Albedo for different grounds

0.15 0.19 0.27 >0.30 >0.50

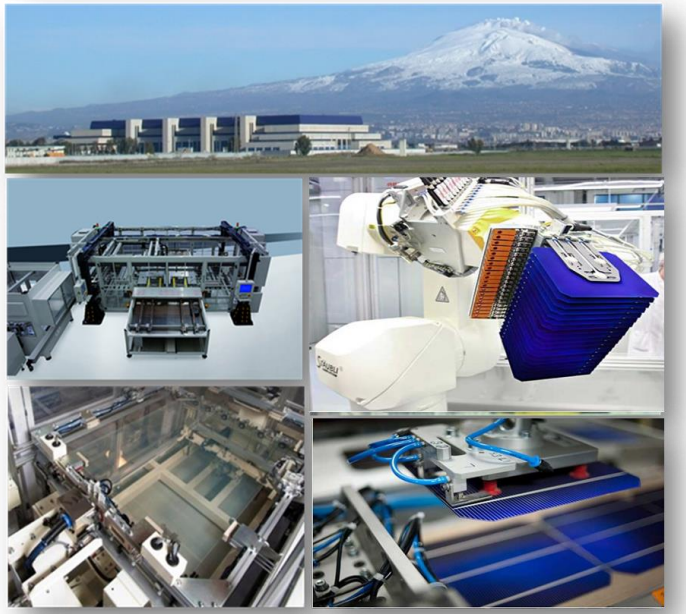
Automated photovoltaic cell and Module industrial Production to regain and secure European Renewable Energy market

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

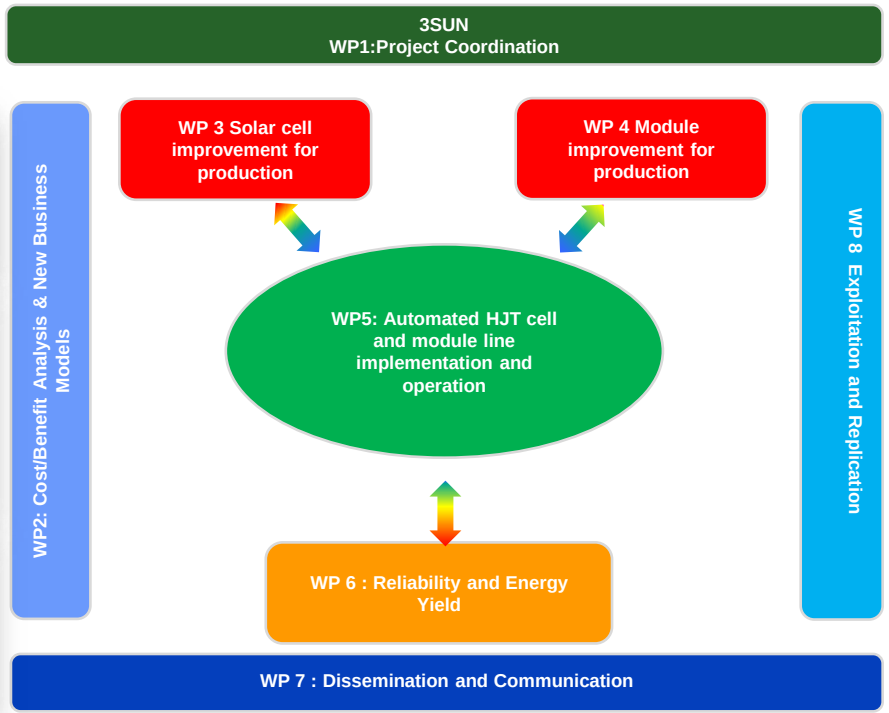
Develop an innovative European and sustainable manufacturing PV line to produce heterojunction technology (HJT) silicon solar cells and module. Scope: to set-up an automated line in real production environment and at the same time to a rapid scale up to more than 200 MWp .

Industry 4.0 Directions:

- High automation level
- Man - Machine interaction
- From digital to real
- Data Analytics



Work Packages 's structure



Bi-facial module prototype:

- **15% bifacial gain**
- **>35 years lifetime**
- **>20% module eff (72 cells/module)**

HORIZON 2020

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Cell Line Development

Path to 23% cell efficiency

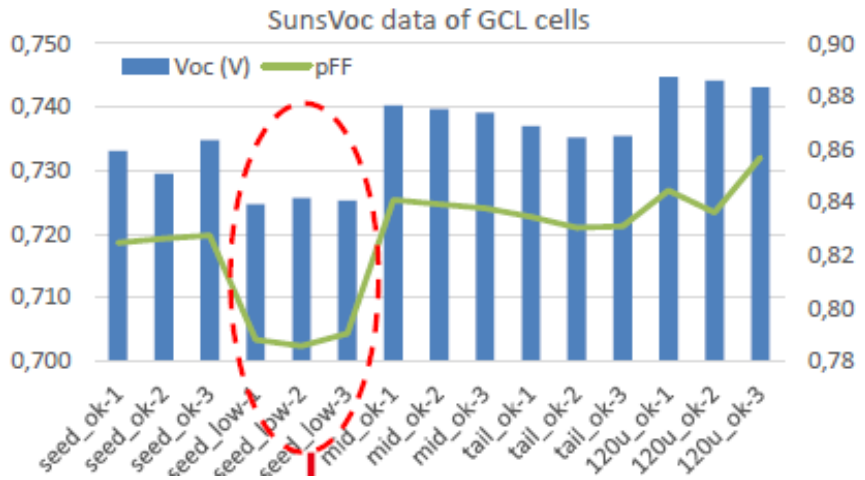
Key activities in progress to 22.5 %:

Studies on BOM with particular focus on wafer and Ag paste

- Full ingot from GCL and full ingot from Longi tested (R&D ingots).
  - Impact of seed area on cell performance studies
- Ag paste optimization→ a new layout that optimizes the usage of Ag maintaining same performances has been developed
  - - 10 % Ag paste usage + 0,01% absolute efficiency

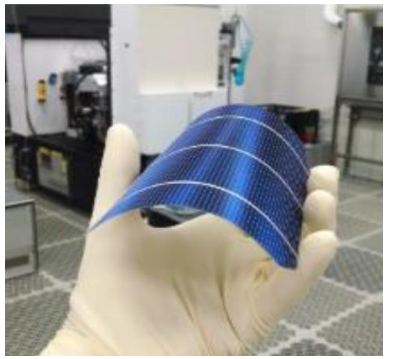
Passivation improvements (micro-doping effect)

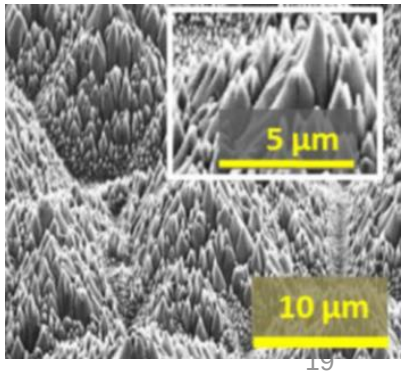
Throughput improvements (PECVD chamber cleaning improvements)



Medium term R&D (Eu Ampere/Other Cooperations)

- High lifetime ingots & wafers. Thicknesses reduction.
- Silicon wafer texturing process improvement: pyramid size for improved conformation low surface optical reflectivity
- New materials for improved passivation: SiC – SiN - Suboxides
- Selective contacts: MoOx,WOx, for holes; LiF for electron
- Advanced TCO materials and deposition methods: IOH, AZO, IWO.
- Advanced metallization: Low Silver content direct printing – Silver-Cu nanoparticles






Thank You!
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