The 3SUN 2.0 Initiative:
Innovative HJT PV Technology for Lowering Energy Costs

Enel Green Power
Innovation & Sustainability
Solar Business Group

Jun 25, 2019

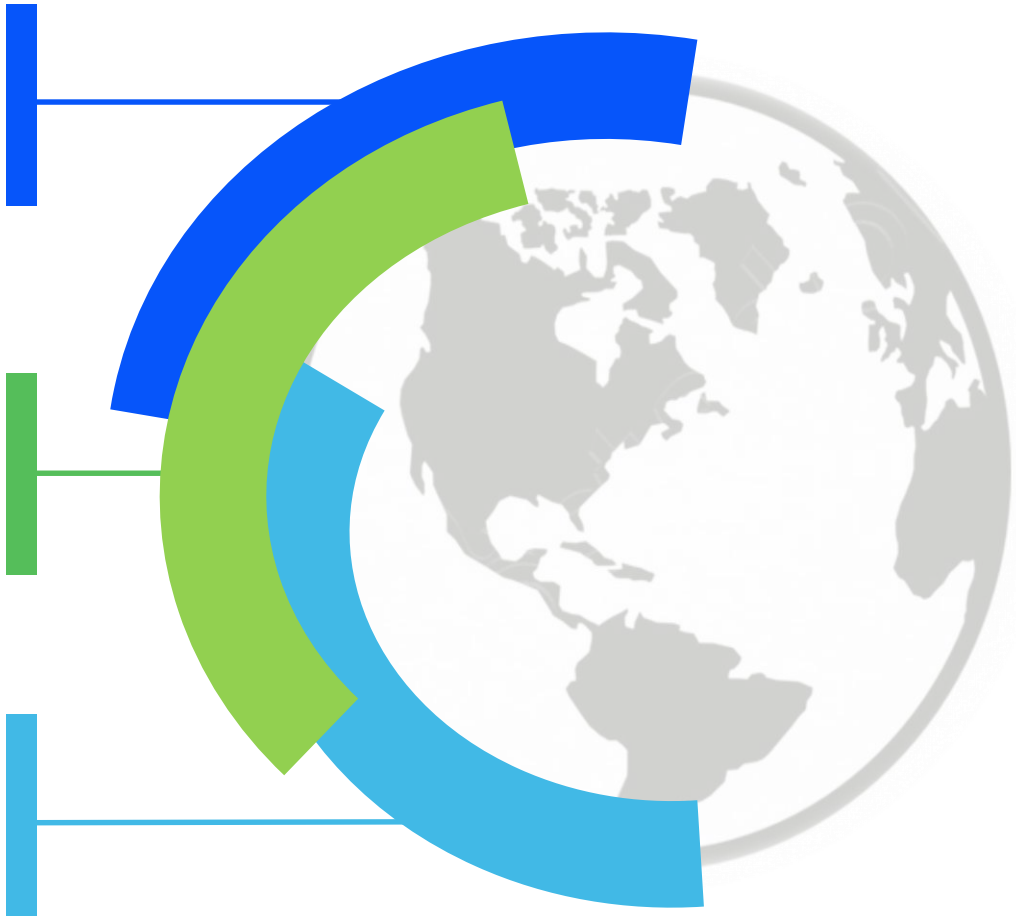
Green Power

Enel Green Power
EGP in the Enel Group

1st **network** operator[1]

World's largest private player[2] in **renewables**

Largest retail **customer** base worldwide[1]



73 mn end users

43 GW capacity[2]

46.5 GW capacity[3]

5.7 GW demand response

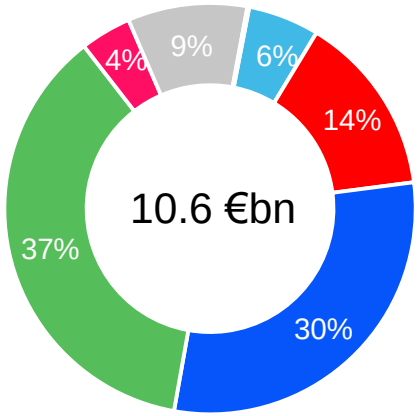
~ 64 mn customers[4]

1. By number of customers. Publicly owned operators not included
2. By installed capacity. Includes managed capacity for 4.2 GW
3. It includes nuclear
4. Includes customers of free and regulated power and gas markets

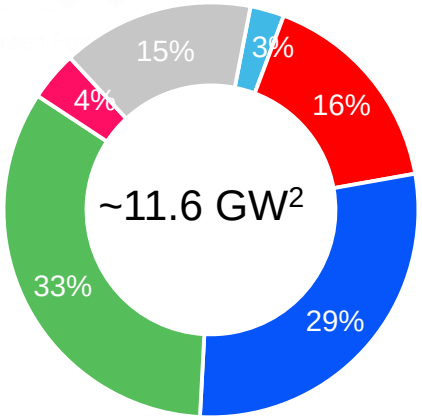
Renewables are the driving force of growth

PV will grow very fast

Asset development capex[1] 2019-21



Additional capacity by geography



Italy | South America | North & C. America
Iberia | Europe & NA | Africa, Asia & Oceania

By technology

70% | 28%

1. Includes 1.6 €bn BSO capex
2. Of which 1.8 GW related to BSO and 0.8GW related to JVs.

3SUN
An Enel Green Power factory

Site numbers

- 115.000 m^2 of usable surface
- 50.000 m^2 manufacturing area
- 3 floors of 16.000 m^2 each
- 300+ permanent employees
- About 7 millions of thin-film modules produced from 2011 to 2017

- Formerly a JV between **EGP, STM and Sharp** (2011 – 2014)
- Controlled by Enel from 2015 to 2018
- Fully integrated in EGP in 2018
- Switched from thin-film to HJT technology in 2018
- Capacity per year 200MW
- **→ COD July 2019**

EGP Vision

New Business Model for 3SUN

Reducing energy cost

€/Wp → €/kWh

In order to compete on the market
→ new model for 3SUN:
full integration within EGP PV value chain.

- **Converting Si thin film technology to an innovative wafer-based PV technology.**
- **Achieving higher energy production in solar plants.**
- **Taking advantage from economy of scale and standardization (Si wafers, glasses, encapsulants...)**

3SUN 2.0

Technology leadership

- Competence on PV tech: materials, costs, industrial process, reliability, equipment.
  - →Know-how for EGP to maintain its leadership on PV value chain.
  - →Innovation foresight: anticipating leading edge technology solutions on PV modules.

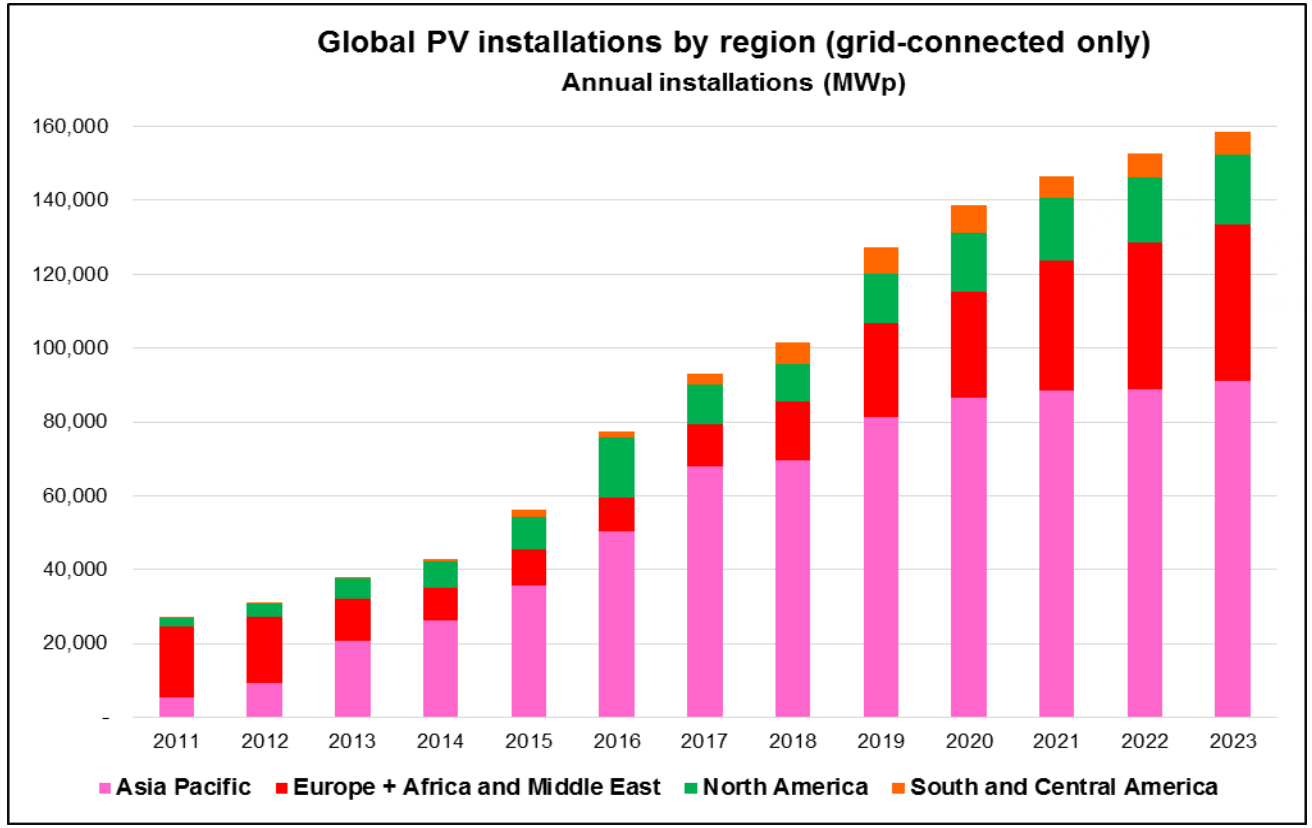
An industrial and PV technology excellence in Europe

- At the forefront of the industrial PV technology.
- Collaboration with the most important research centers in Europe, US and Canada.

PV Market and Technology trends

PV Market

Market Size for European PV Production



Source: IHS Markit - 2019

Europe + Africa and Middle East

➔ Annual installations will increase from 25 GW in 2019 to 42 GW in 2023 with significant growth in market share: 20% in 2019 to 27% in 2023.

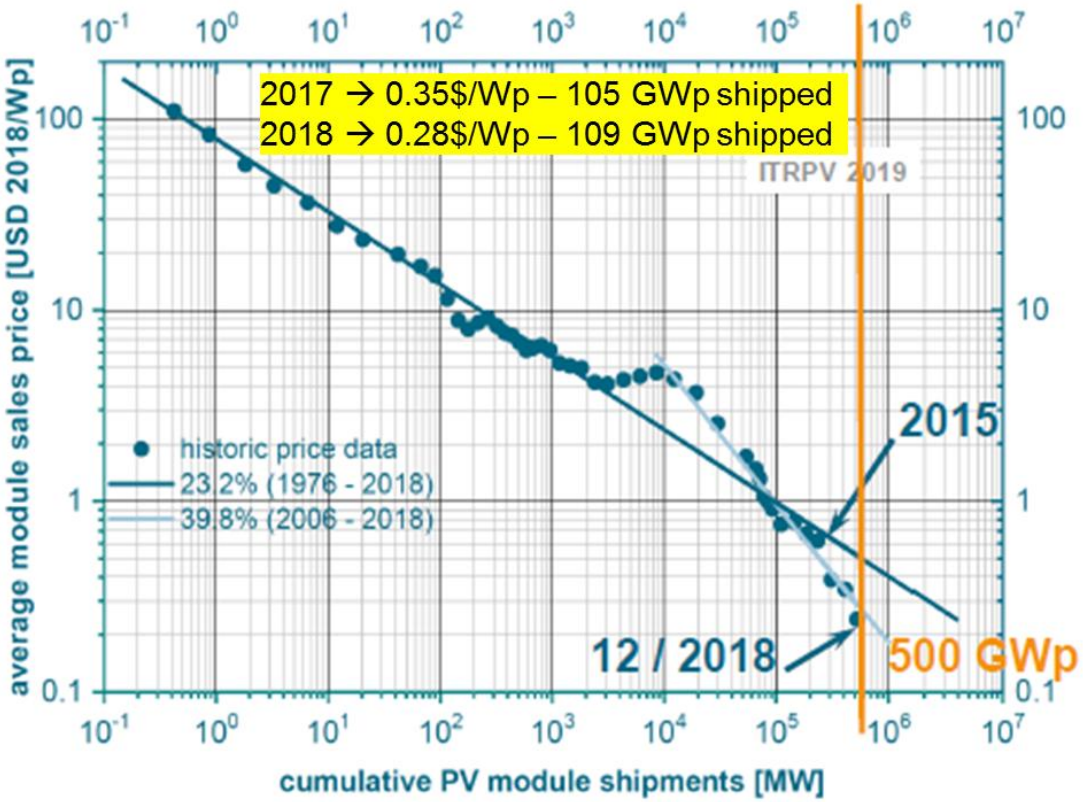
➔ The trend shows that **European PV manufacturing can have a significant reference market** well distributed among the different segments of the market (residential, commercial and utility scale).

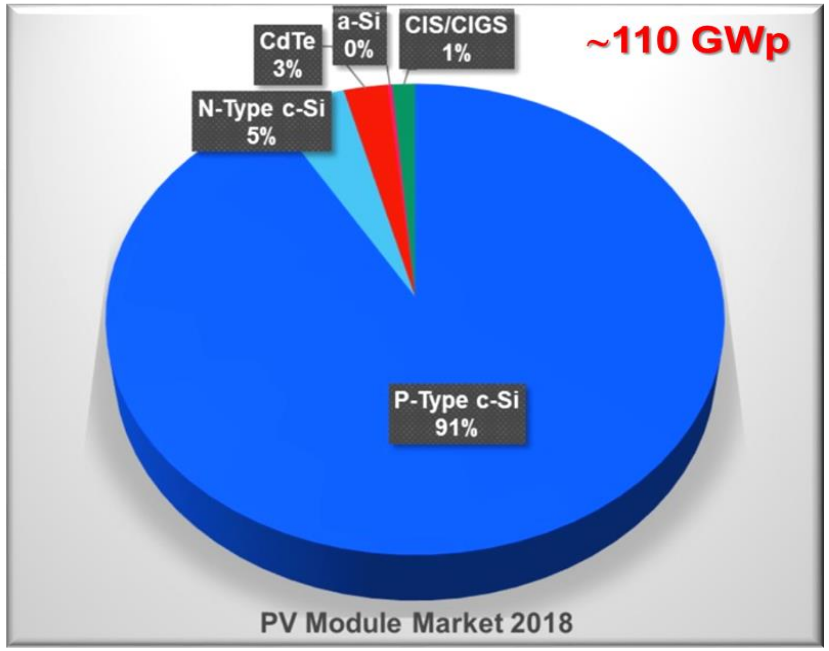
World PV market

➔ The annual installation, over 100 GW in 2018, will increase to reach about 140 GW/year in 2020 and about 200 GW/year in 2023.

➔ Europe PV installation forecast shows that it will be always over 15 GW/y.

PV Market





Source IHS Markit 2018

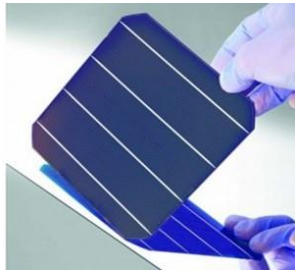
c-Silicon dominates the market!

HJT Bifacial Technology:

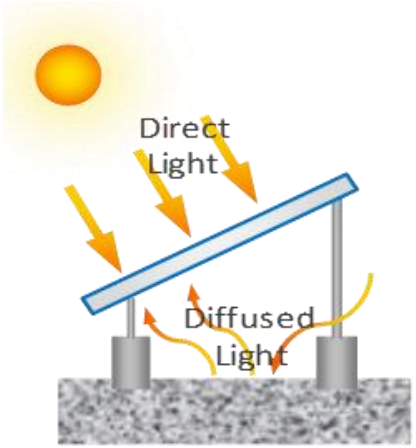
An Innovation Promised to European Industrial Future

EGP Vision

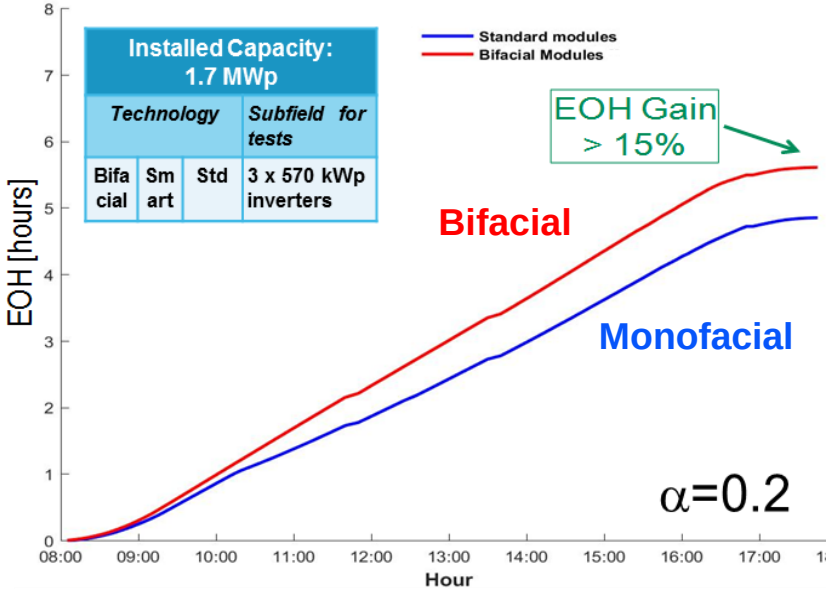
Increase Energy Gain → Reducing LCOE with Bifacial Modules



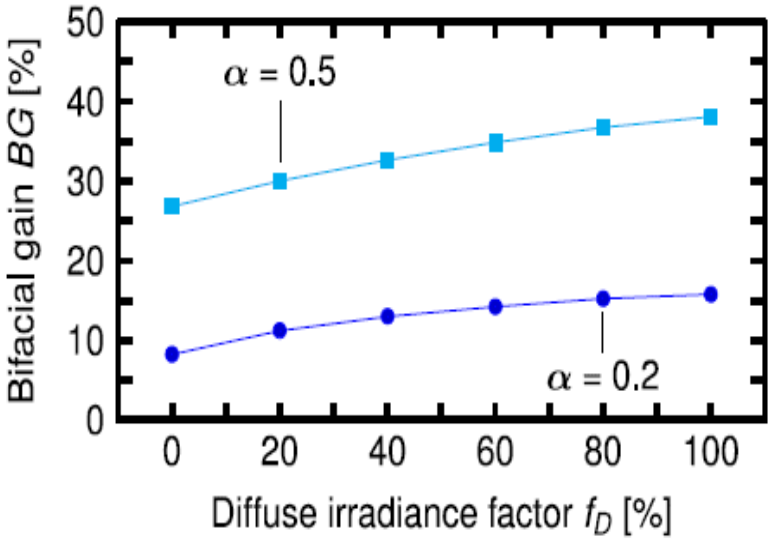
Bifacial



On the field: La Silla – Atacama Desert (Chile)



Improving albedo



Albedo
(reflectance of the ground)

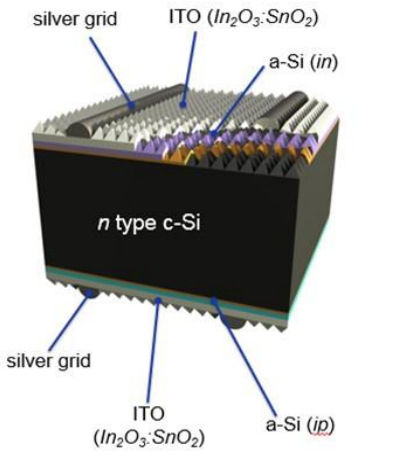
0.19 0.27 >0.30 >0.50

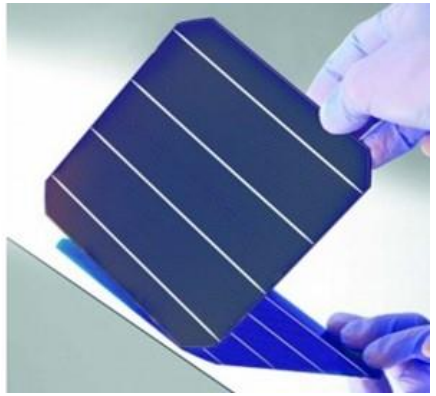
(Increase energy from +10% up to +40%)

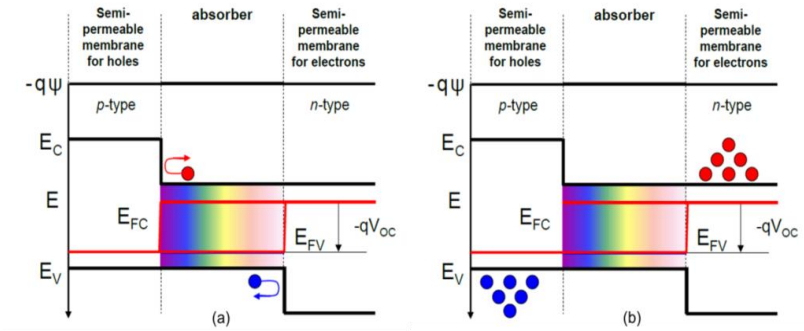
PV Modules Technology

HJT: Innovative Technology for Reducing LCOE

Silicon Hetero Junction Technology (HJT)







The a-Si / c-Si junction builds up semi-permeable barriers which optimize the collection of photo-generated charges
→ higher cell efficiency

Characteristics of HJT	Advantages
-Easiest and symmetric process for bifacial cells, - Reduced number of process steps	-Low manufacturing costs and reduced energy consumption, related to cell process -High compatibility with automation
Low temperature process, 200°C, enabling thinner wafers	Less silicon → lower material costs.
High passivation and selective contacts	Lower recombination losses → Higher Efficiency
Low thermal coefficient due to the excellent passivation of a-Si:H	>8% energy generation in warm climates with respect to mainstream c-Si
Lower yearly degradation	0.2% → 0.1%/year with possibility of further reduction
Higher bifacial factor: rear/front 90÷95%	Lower LCOE !!! In higher albedo grounds → 10 ÷ 20 % reduction with respect to conventional

HJT manufacturing process

HJT vs standard

N - PERT	P - PERC	HJT
Inspection	Inspection	Inspection
Texturing	Texturing	Texturing
Diffusion	N Diffusion	A-Si(i)a-Si(p) rear
PSG-REM	PSG-REM	TCO front/rear
Oxide rear	AlOx rear	Print front
A-Si/pcSi/ rear	SiNx rear	Print rear
Etch backrear	SiNx front	Test/ Sort
AlOx front	Laser opening	
SiNx front	Print front	
SiNx rear	Print rear	
Print rear	Firing	
Print rear	Test/ Sort	
Firing		
Test/ Sort		

13 Steps

More process steps
High Temperature
Diffusion 800°C
Thickness >150 µm

Efficiency:
21.5 ÷ 22.5 %

11 Steps

More process steps
High Temperature
Diffusion 800°C
Thickness >150 µm

Efficiency:
21.0 ÷ 22.0 %

7 Steps

Less process steps
Lower Temperature
Deposition 200°C
Compatibility with Thickness <100 µm

Efficiency:
22.5 ÷ 24.0 %

HJT process has a simplified process flow and utilizes low temperature (<200°C) for deposition and curing:

- ➔ Lower energy consumption in manufact
- ➔ Reduced use of lead in soldering
- ➔ Compatible with thinner wafers (<100µm) . Lower silicon consumption

➔ Can be well matched with future developments:

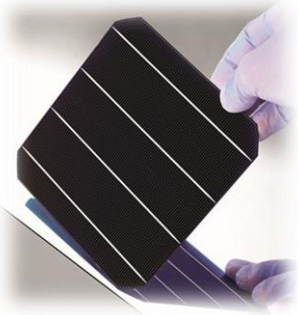
- Tandem or 4 terminal structures
- Selective contacts implementation
- Compatibility with copper
- Implementation of nanotechnolog

3SUN 2.0 Program

3SUN 2.0
Innovation in PV technology

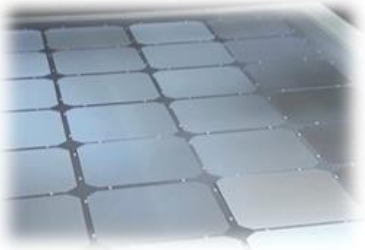
Three times innovative

- Novel technology used to fabricate high efficiency solar cells
  - → ***Silicon Hetero Junction (cell efficiency >23%)***
  - → ***Symmetric cell (>90% bifacial)***



- New technology to realize modules that ensure higher energy generation
  - → ***High power modules (power 385 ÷ 405 W)***
  - → ***High bifacial and thermal stability gain (additional energy +30%)***

- Most advanced manufacturing automation and digitalization systems
  - → ***Higher quality and throughput → reducing manufacturing costs***

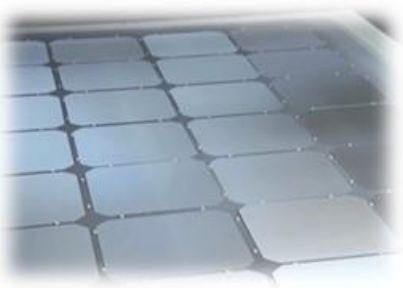


3SUN 2.0 Program

Overall Plan

Jul 2018
Bifacial Module Line
Only Assembly
Commercial Bifacial Cells (PERT)
AVG Pmax= 345Wp
Capacity 80MWpa

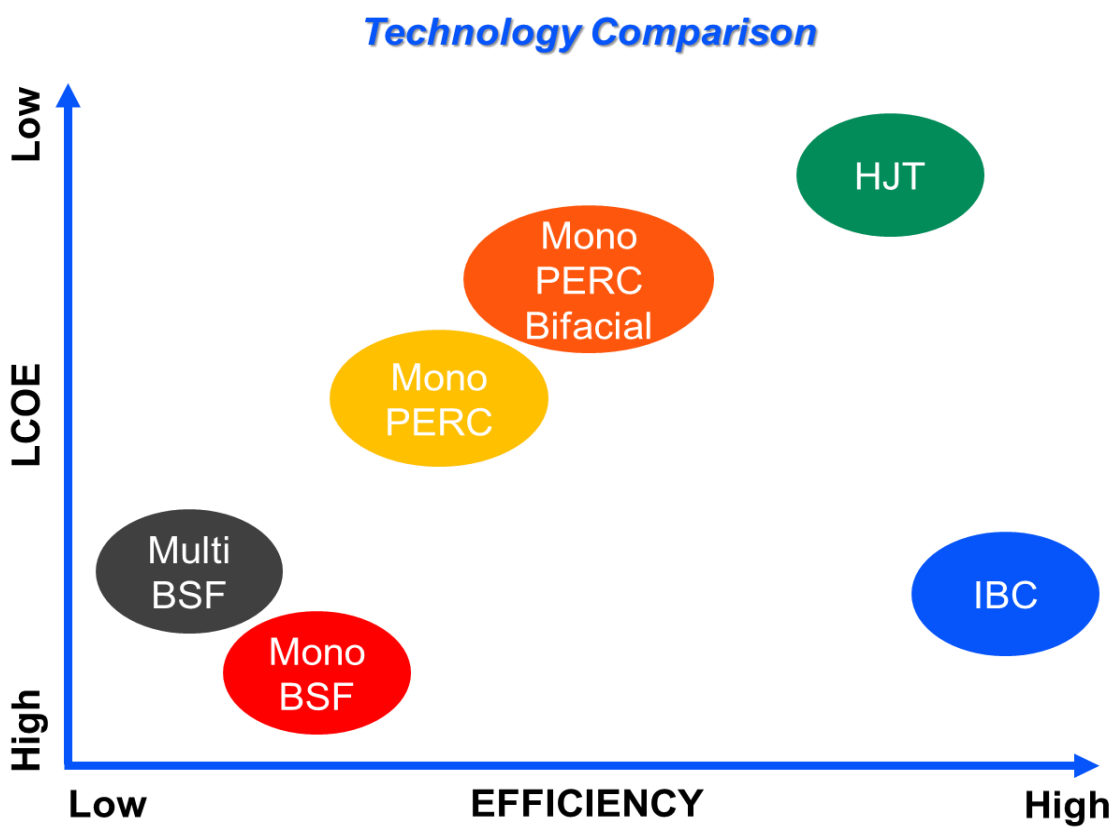
Jul 2019
HJT Cell and Bifacia Module Line
AVG Pmax= 385Wp
Manufacturing
Capacity 200MWpa



From 200MW to 1 GW

PV Market

HJT: an innovation promised to European future



HJT has the potential to put Europe durably back on the map in PV manufacturing.

➔ Higher conversion efficiency,

➔ More annual electricity production (bifacial + thermal stability)

Locating factories in Europe, production costs can be competitive with low-cost Asian producers

provided that

capacities > 1 GWp/year
to achieve proper economies of scale.

Increasing Volumes

From 200MW to 1GW

- Current costs of HJT at 200 MW/y are 15-20% higher than mainstream.
- LCOE model allows HJT to be competitive even at 200 MW scale (residential and utility scale with high albedo grounds).
- Increasing volumes from 200 MW to 1 GW/y leads to further costs reduction of 20÷25% → competitive in overall utility scale and residential.
- → Innovative HJT technology can win the competition with mainstream.
- Current 3SUN 200 MW factory can be the starting point for a 1GW factory in Europe.

3SUN 2.0
Factory Layout

Available area for additional 800MW Cell Lines.

New Tools with higher throughput

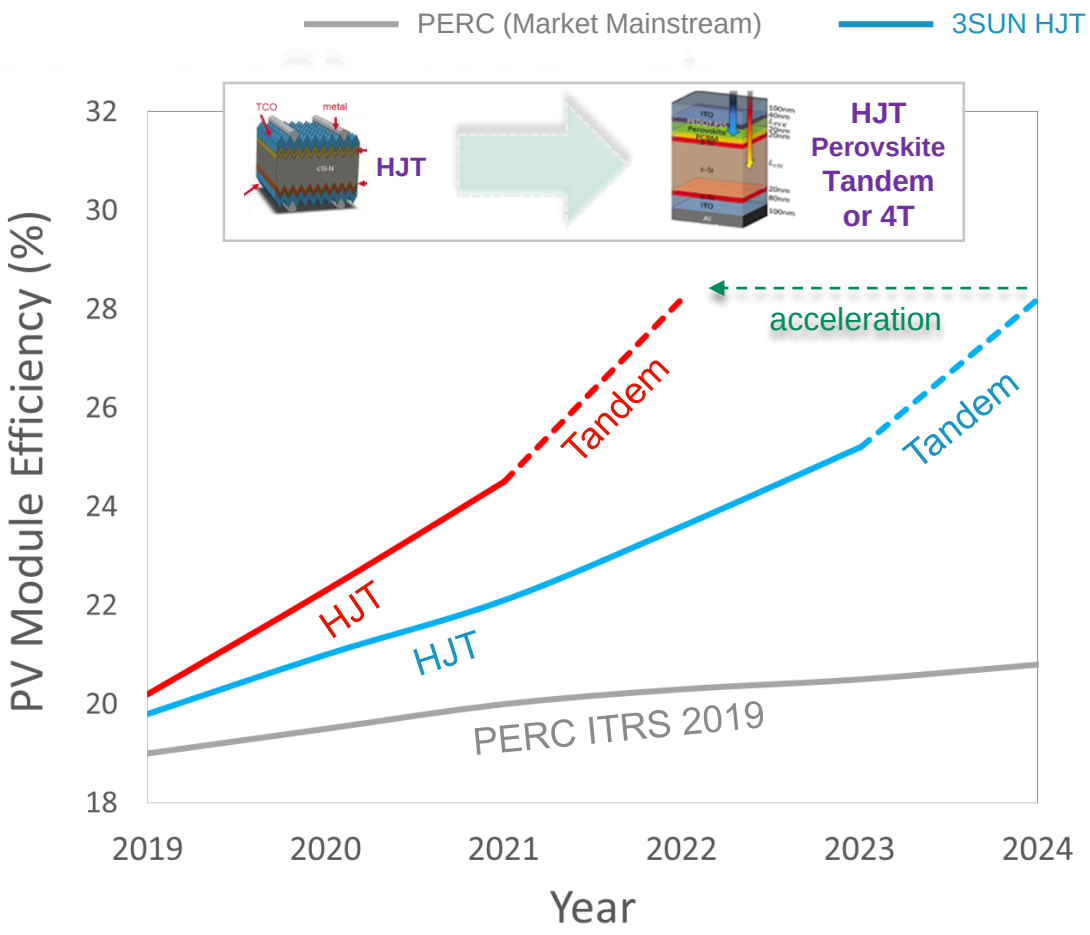
PECVD

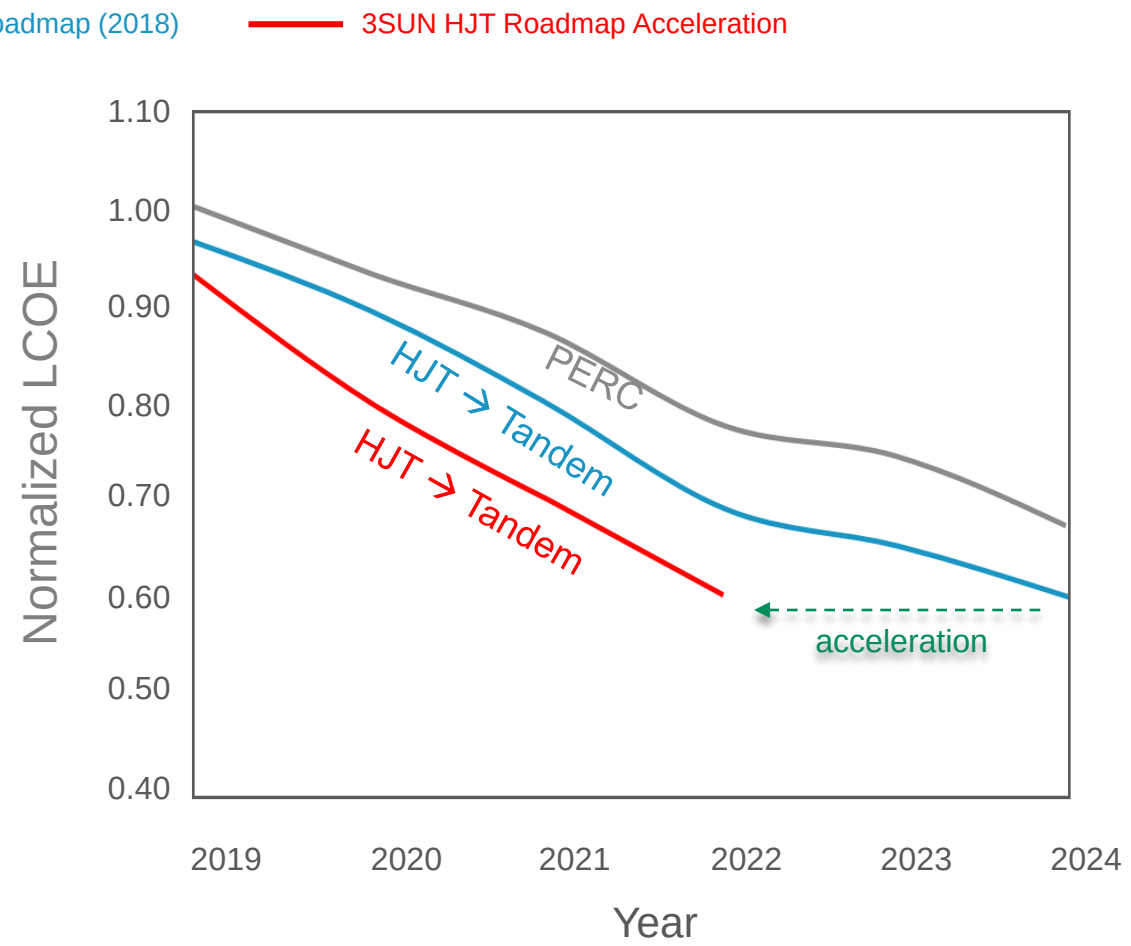
PVD

R&D and Technology Roadmap

Technology Roadmap

Accelerated Roadmap: Efficiency and LCOE





Target module efficiency: up to 28%+in 2022

Target LCOE reduction vs PERC: about -20% in 2022

Theoretical and Practical Limits

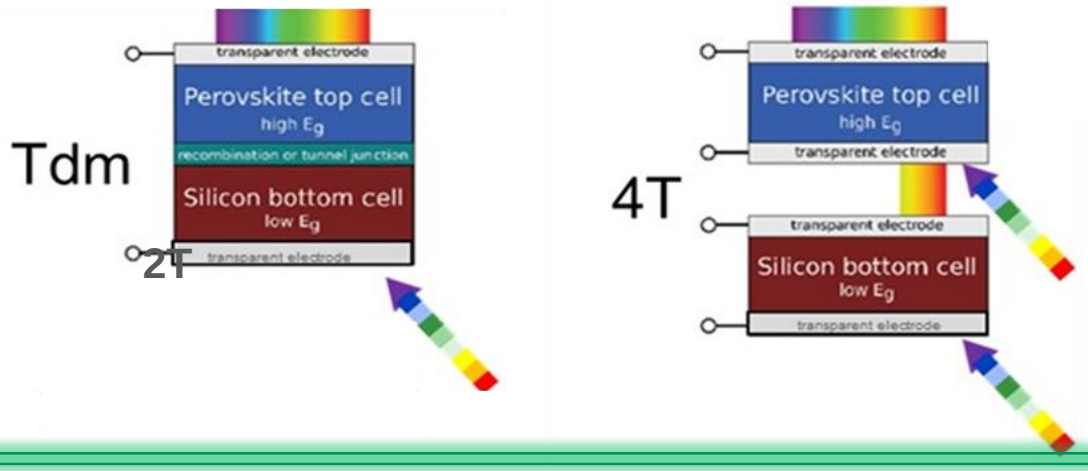
United We Stand: From Single to Tandem Junctions

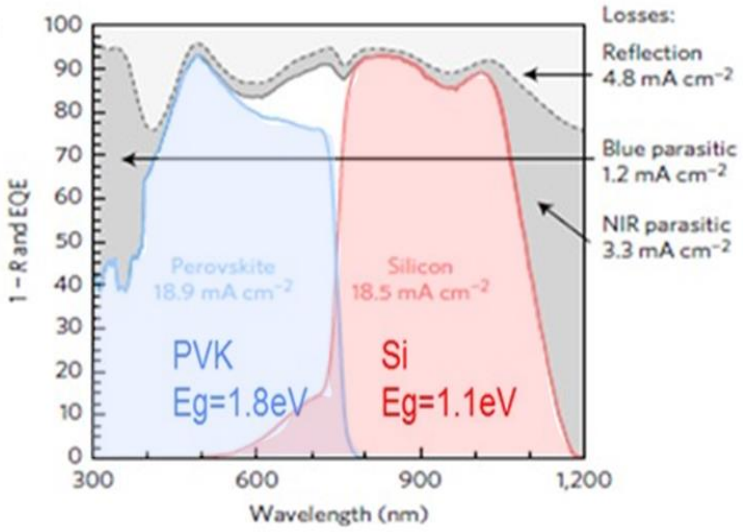
23% Best Si bif

27% Si practical limit

29% Si Theoretical limit

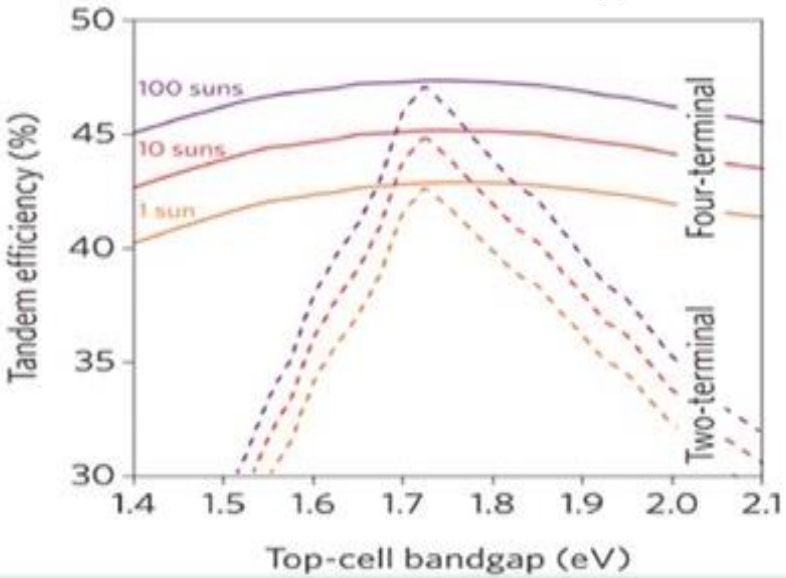
> 30% Tandem Cell





Increase light spectrum

Coupling top cell with larger band gap (perovskite) with botton cell with smaller band gap (silicon HJT).



Matching

Tandem structure (two terminals / 2T) needs top and bottom cell current matching → limited window

4T (four terminals) voltage matching is possible → large window

Thank you
enel
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