

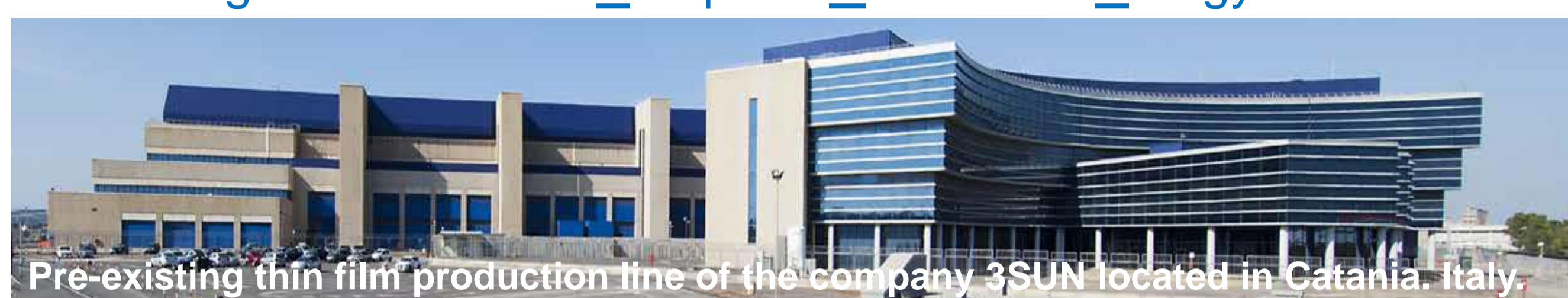
THE AMPERE PROJECT: AUTOMATED PHOTOVOLTAIC BIFACIAL CELLS & MODULES INDUSTRIAL PRODUCTION TO REGAIN AND SECURE EUROPEAN RENEWABLE ENERGY

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1. Context

AMPERE = **A**utomated photovoltaic cells & **M**odules industrial **P**roduction to regain and secure **E**uropean **R**enewable **E**nergy market

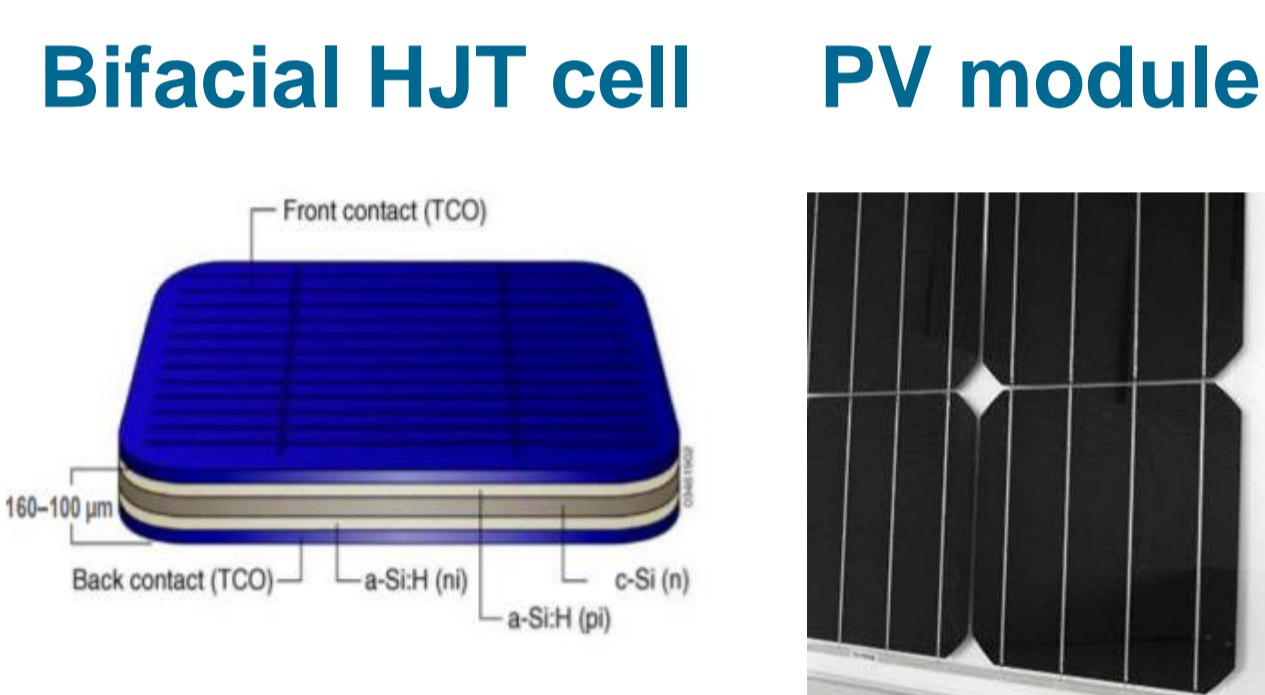


- A large European partnership (H2020) started in May.2017 for 3 years
- Demonstration of an innovative and sustainable manufacturing of bifacial heterojunction modules with low production costs
- Setup of a 100 MWp/y full-scale automated pilot line in Catania, Italy
- Rapid scale up to 250 MWp/y and roadmap towards the GWp factory



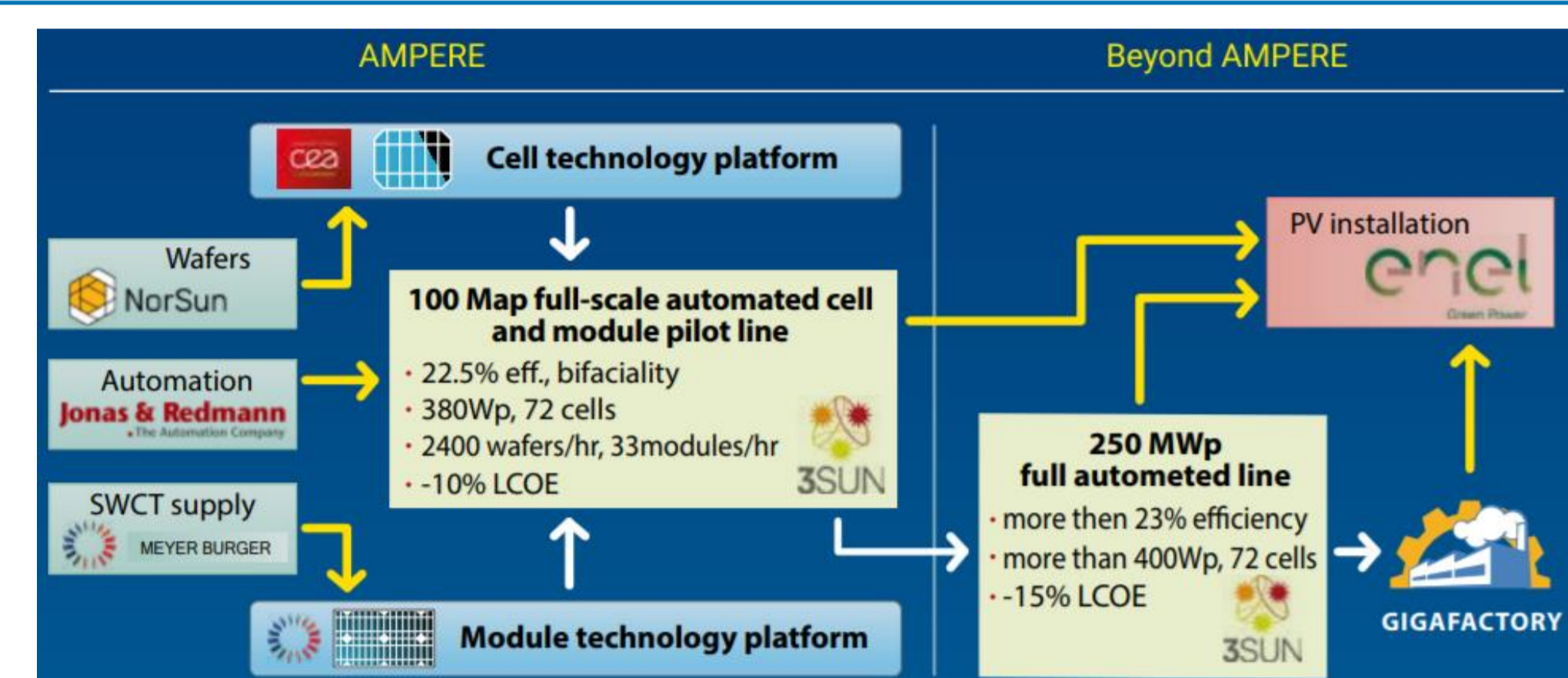
2. Technology

- Proven high-efficiency n-type silicon heterojunction (HJT) bifacial solar cells (156.75 cm x 156.75 cm)
- Reliable large (72 cells) glass/glass photovoltaic (PV) modules with a bifacial architecture



3. Goals

- LCOE reduction of at least -15% compared to conventional PV mc-Si technology



4. Current studies & results: some examples

Silicon ingots and wafers

- Seed-to-tail full ingot silicon material analysis and integration in HJT pilot line for performance evaluation of all wafers at cell level
- $T_{bulk} / Res > 1$ ms/ $\Omega \cdot cm$ demonstrated on whole ingots
- 130 μm -thick as-cut wafers with no loss in performance vs 160 μm ones

Solar cells

- Detailed analysis of current HJT performance losses
- Material improvements, advanced characterizations and simulations
- Delivery of 1st generation of selected key technologies for 22.5% efficiency HJT cells, and starting development of 2nd generation to reach 23.5%
- Industrial batch records 21.8% efficiency in average

Average	Voc (V)	Jsc (mA/cm ²)	FF (%)	Ncell (%)
AMPERE batch	0.731	37.3	79.9	21.8

- Innovative developments for next generation production lines: soft PECVD & PVD process, copper plating, reduced consumption, half/quarter cells...

PV modules

- Definition of cell-to-module (CTM) performance criterion for the comparison of HJT cell with busbars (BB) or without (Smart Wire: SWCT)
- Evaluation of SWCT Indium-free wire modules performances and reliability
- 2x2-cells modules production: reliability testing & failure modes analysis
- Bill of Material (BOM) identified for "initial generation" HJT modules

Illuminated side	Voc (V)	I _{sc} (A)	FF (%)	Pmax (W)
Front side	53.2	9.17	75.8	370.0
Back side	53.1	7.89	76.3	319.3

- Module mechanical behavior simulations & tests (clamps dimensions, ...)

Automation

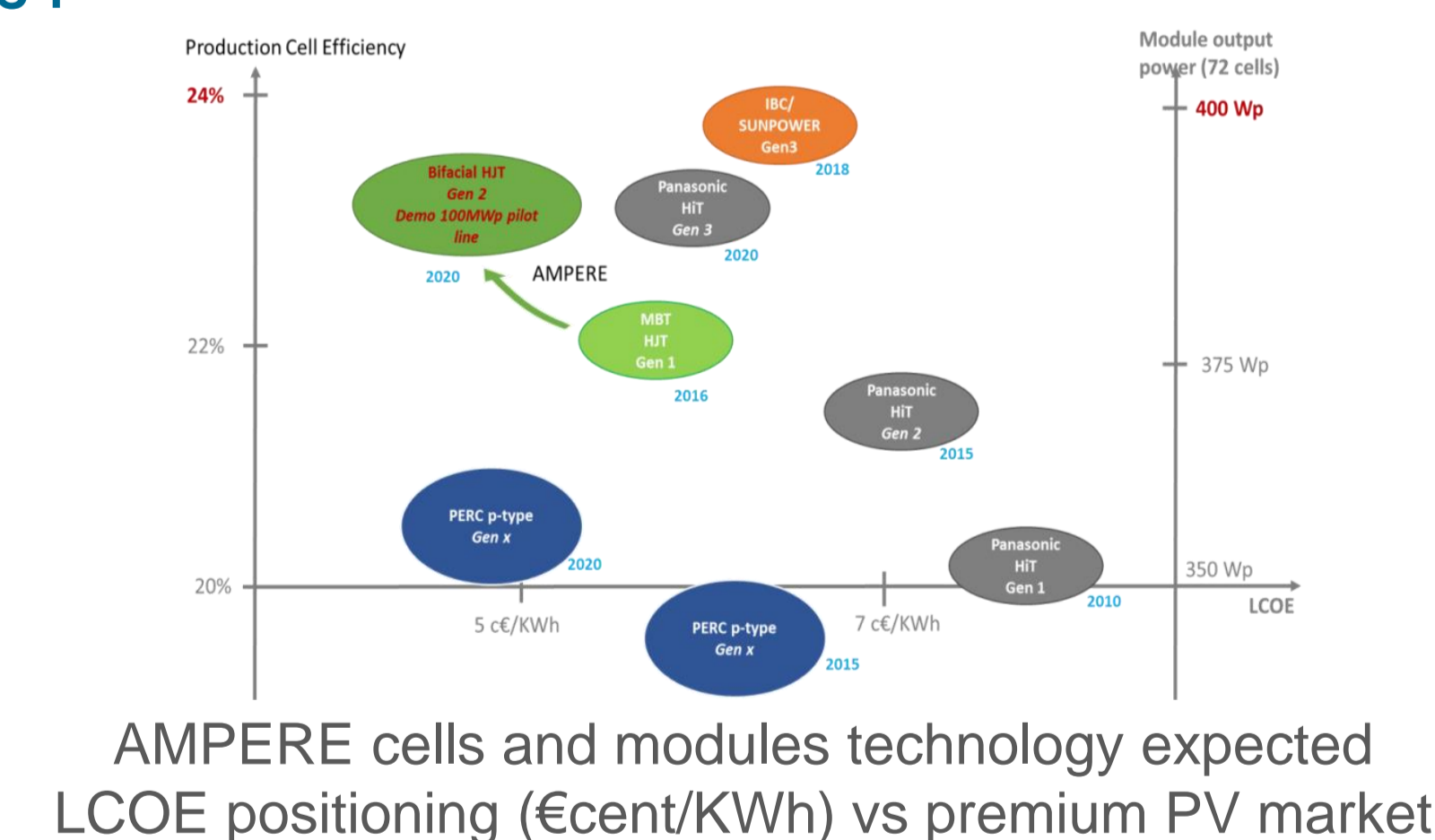
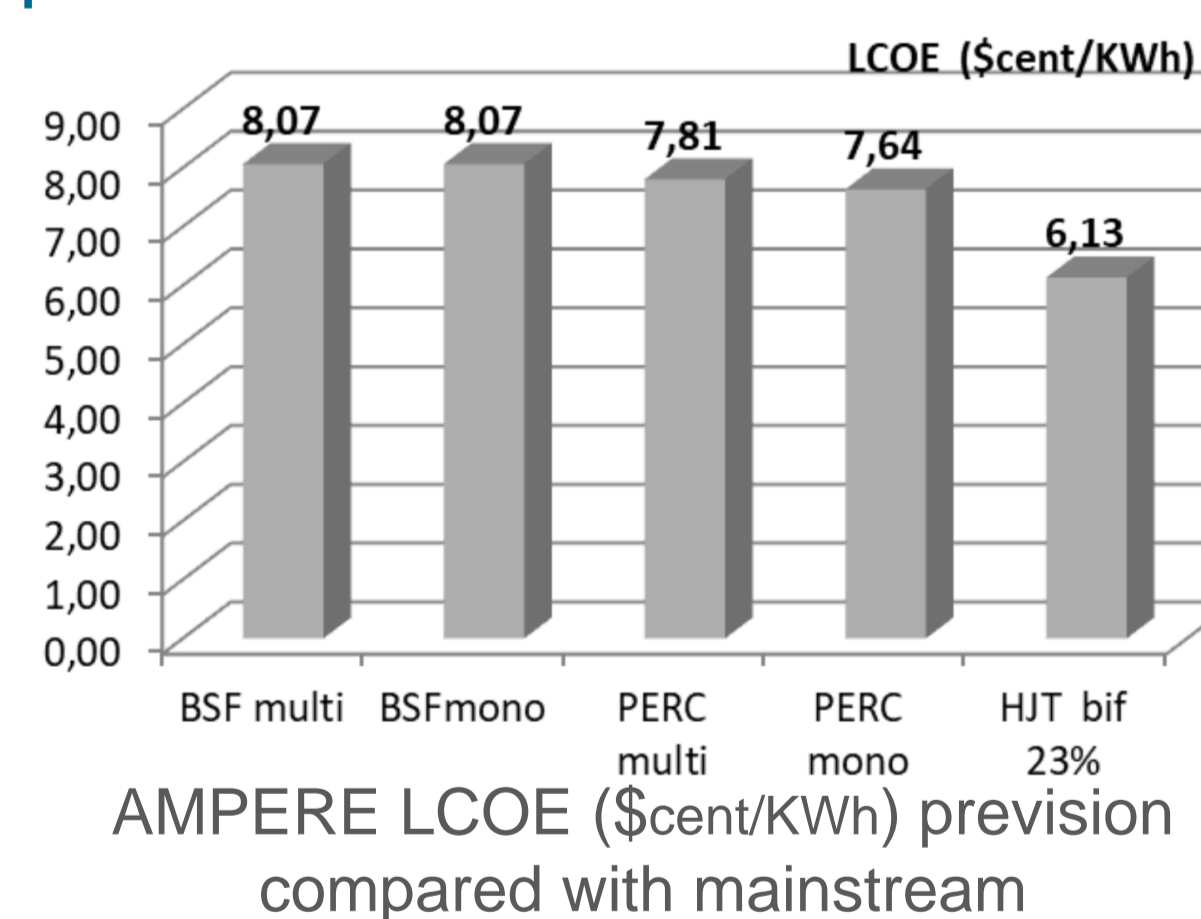
- Evaluation of the re-use of the existing process tools at EGP site (Catania) for HJT application
- Industrial cell-line designed with high performance handling systems & current implementation in EGP factory

Reliability and production yield

- Modules round-robin among 5 partners and reliability tests
- PV demonstrators specifications for Catania (IT) & Cadarache (FR) sites
- On-going outdoor installation of AMPERE modules "initial generation" for performance monitoring evaluation

Cost & benefit analysis

- Cost benefit analysis and new business model including Life Cycle Assessment (LCA)
- Forecast of an average sales price of 0.3 \$/Wp in 2022 with an additional premium bonus about 30% for HJT



Dissemination

- Training about "New HJT solar cell pilot line" to the world of education (students) and industry (workers), in July.2018, ~35 people

5. Conclusion

- Moving up the TRL of standard HJT technology into the European industry in good progress
- R&D activities focus in solving production issues, yield, equipment and improvement through a unique consortium of top-ranked partners
- New generation of innovative n-type silicon solar cells and modules in development with improved efficiency and reliability

6. Some outlooks

- Continuous technologies evaluation & selection for industrial transfer
- Thin cells (110 μm) breakage rate evaluation and cost impact
- HJT cell efficiency over 23%_{average} on production batches
- New selection of material for the BOM of "final generation" HJT modules
- Benchmark of worldwide PV industrial manufacturing materials
- Monitoring of PV systems performance & benchmark studies
- LCA, environmental & societal assessment reports