# Bifacial heterojunction PV modules: Highest energy yield available… and how to measure that

**Module performance** | Recent technology advances and improved industrial processes have made silicon heterojunction one of the most attractive PV technologies, helped by its inherent bifaciality, which offers among the highest levels of bifacial gain available. Researchers from CEA-INES and Eternalsun Spire explore the performance stability and measurement of bifacial heterojunction modules under real life conditions, benchmarking them against PERC modules as the industry workhorse

Silicon heterojunction (SHJ) solar cells have fewer manufacturing steps (five to seven) that are simple to control (regarding homogeneity and defectivity) compared to standard passivated emitter and rear cell (PERC) cells. During recent years, SHJ technology has been rapidly improving on manufacturing readiness with module efficiencies beyond 24%, the availability of high-quality, low-cost thin n-type c-Si wafers, new metallisation and interconnect solutions as well as that of cost-effective mass-production tools for PECVD deposition of amorphous silicon and PVD deposition of transparent conductive oxide (TCO) layers [1]. There are now at least 20 research institutes and pilot or production lines demonstrating efficiencies above 23% as baseline for cells on 6” wafers (see Figure 1). Last but not least, SHJ technology offers cells that are inherently bifacial, with a bifaciality of around 90-95%, whereas PERC cells are limited to 70-80% bifaciality [2].

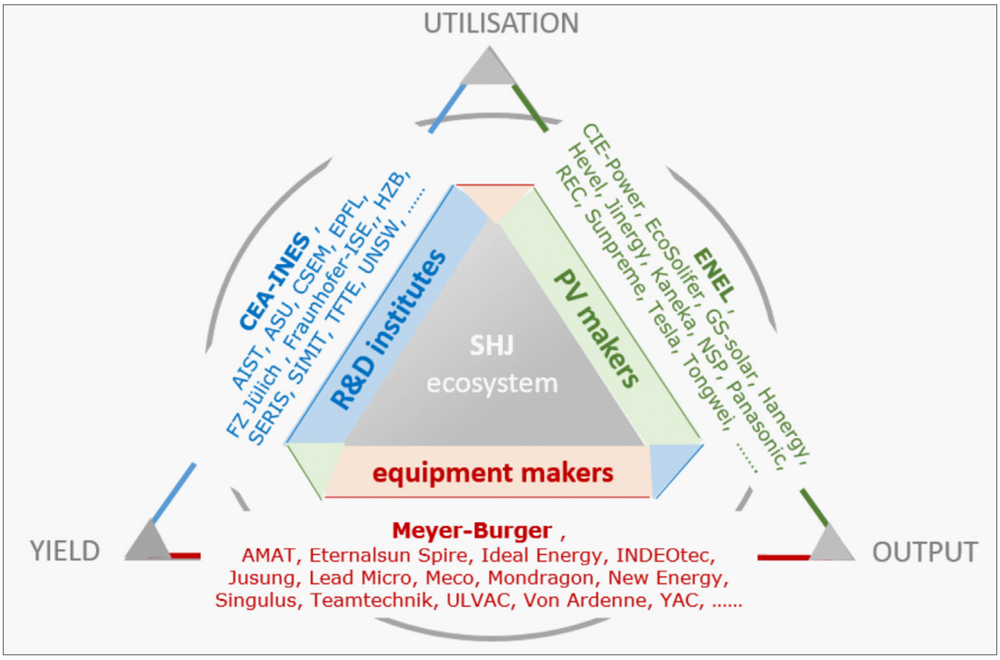


**Figure 1. The future of SHJ manufacturing is ecosystem driven**

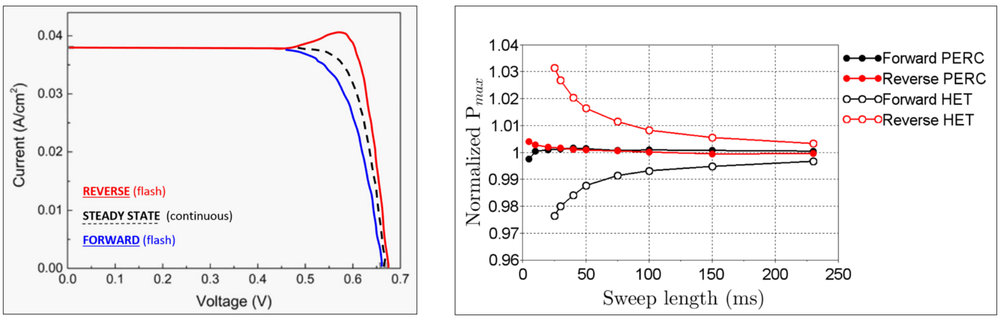


**Figure 2. Left: IV curves for forward (blue) and reverse (red) short pulse sweeps compared to a steady-state IV measurement. Right: $P_{max}$ performance measurement for PERC and SHJ modules as a function of pulse length on an Eternalsun Spire long-pulse solar simulator. Measurements converge at pulse lengths above 200ms, not attainable for conventional flash solar simulators**

## How to accurately measure heterojuncion efficiency

New technologies and efficiencies may require new tools ready to measure them. Traditional short pulse tunnel flash simulators bring a huge offset to SHJ IV-measurements. This is illustrated in Figure 2 and it is due to the capacitive effect inherent in high-efficiency, high $V_{oc}$ PV modules. The outcome of measuring with short pulse tunnel light is that the real power might be overestimated or underestimated, depending on the direction of the IV sweep [3]. Even correction methods such as dynamic IV add an uncertainty of ±0.6 % to the measurement [4], equivalent to ±2.4W in a 400W module.

However, the measurement challenges for high-performance (and high-capacitance) SHJ modules can be resolved through the use of long pulse flashes (over 200ms). These long pulses can be obtained with a tabletop solar simulator such as the SPI-SUN 5600 SLP from Eternalsun Spire, shown in Figure 3 and suitable for R&D, certification and manufacturing.

Figure 3. Left: SPI-SUN 5600 SLP table top simulator from Eternalsun Spire. Right: the same setup with an added temperature control box on top, ready for single-sided bifacial measurements

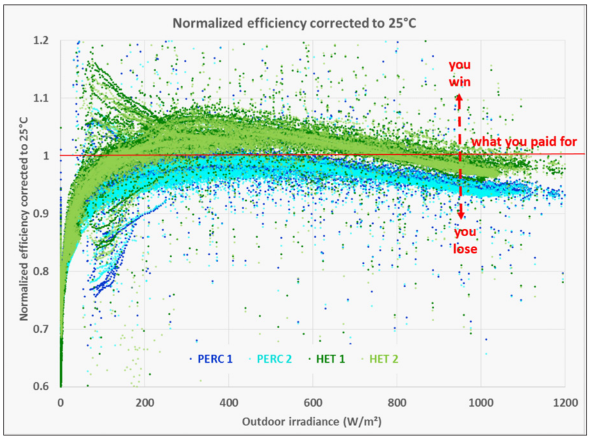


**Figure 4. Temperature-corrected module efficiency versus irradiance (in W/m²) obtained outdoor, with one data point per minute taken during one month (April 2018) at the site of CEA-INES in Bourget-du-Lac (France). Two commercial monofacial PERC modules (in blue) are compared to two heterojunction modules (in green) that had been manufactured at the CEA-INES pilot line. The efficiency is normalised relative to the indoor STC efficiency. The financial break-even line is indicated in red, showing SHJ modules to outperform PERC**

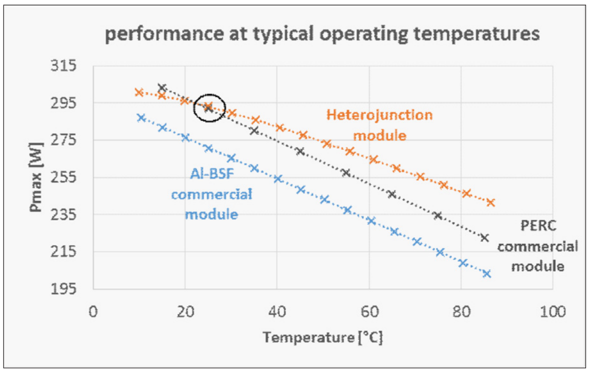


**Figure 5. $P_{MAX}$ under one sun versus temperature for SHJ, PERC and Al-BSF modules measured on Eternalsun Spire labflasher with temperature box. The black circle points to the performance of SHJ and PERC at STC conditions (25°C)**

## Superior performance for SHJ at low irradiance and high temperatures

It is important to know how PV modules perform under lower than the standard STC irradiance of 1,000W/m². Figure 4 shows the results of the outdoor monitoring of PERC modules and SHJ modules over the period of a month at the test site of CEA-INES in Bourget-du-Lac (France). The PERC modules were from a Tier-1 supplier and the SHJ modules were manufactured at the pilot line of CEA-INES in collaboration with Meyer Burger and 3SUN/ENEL. In these outdoor conditions, SHJ technology is seen to give higher efficiencies than PERC over the whole range of irradiance.

The outdoor efficiencies in Figure 4 are normalised to the efficiency measured indoors under STC conditions. This STC efficiency drives the module cost invested in a PV project. So with modules above the red 'break-even' line the project performs financially better than estimated, below this line it performs worse.

The values in Figure 4 have been corrected towards a 25°C operating temperature using the temperature coefficients of the modules. This temperature coefficient is technology dependent and forms a determining factor on the outdoor yield performance. Correct determination of this temperature coefficient is tedious and needs careful procedures and equipment to reduce measurement errors and uncertainties to a minimum. An example of such a temperature coefficient for SHJ, Al-BSF and PERC modules is shown in Figure 5.

Figure 5 shows the performance of SHJ, PERC and Al-BSF modules, measured with the setup shown in Fig. 3 (right). It can be seen that although both PERC and SHJ modules are purchased with a power rating of 295W, SHJ actually delivers 5% more power under realistic temperature operating conditions (>40°C).

Finally, Figure 6 shows the test procedure needed to accurately characterise the power performance under one sun at different temperatures of a PV module of any technology. This procedure can be performed in a setup such as the one in Figure 3 and deliver the results shown in Figure 5.

This SPI-SUN 5600 SLP table top simulator with temperature control box

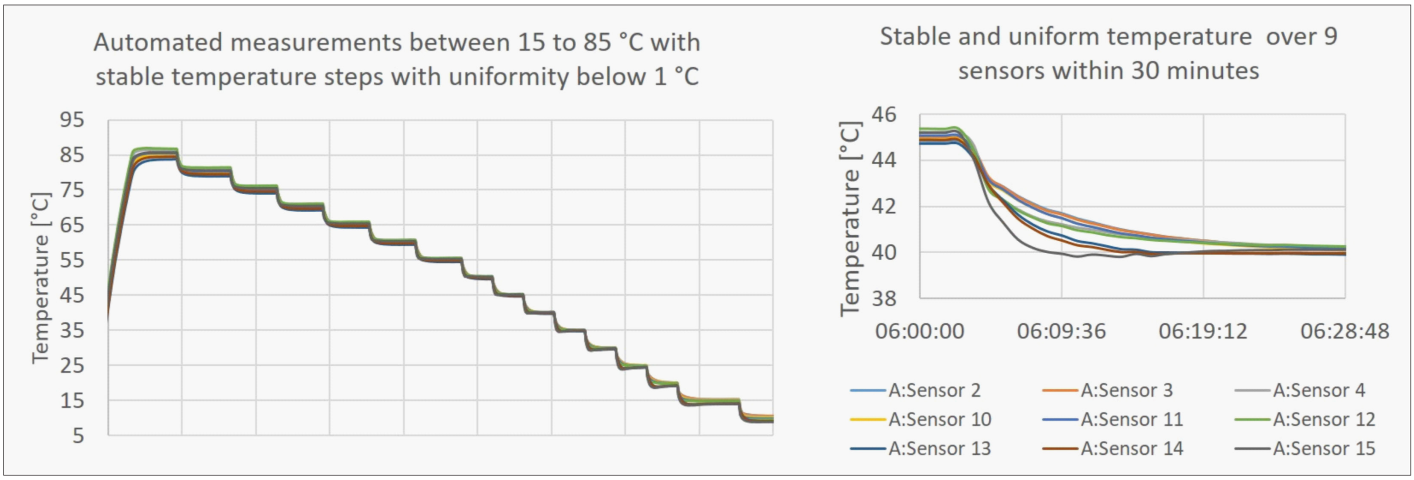


**Figure 6. Temperature of the PV module on nine points across the module versus time during the $P_{MAX}$ versus temperature test shown in Figure 5. Note that the temperature is stabilised for accurate $P_{MAX}$ measurements. Test performed on the Eternalsun Spire setup shown in Figure 3**

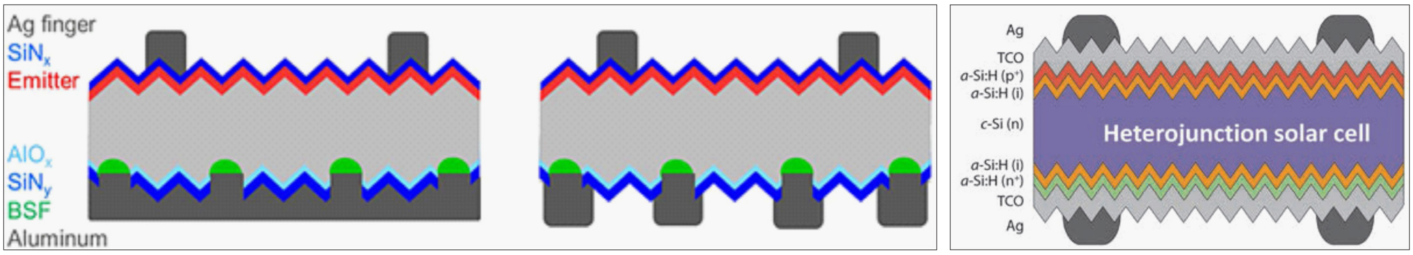


**Figure 7. Layout of monofacial PERC (left) and bifacial PERC+ cell (middle) and heterojunction cell (right)**

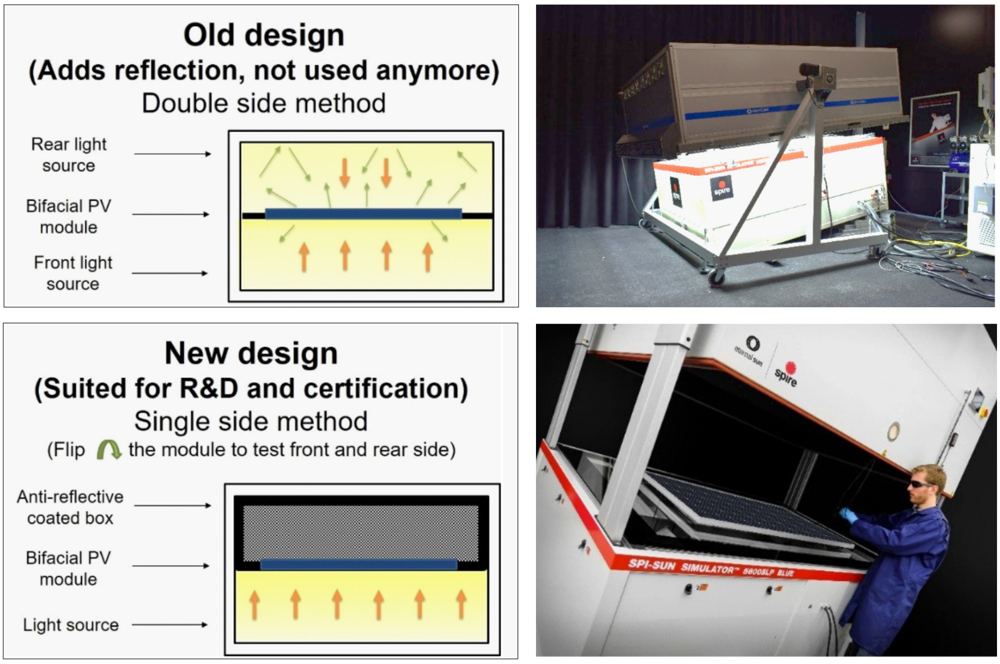


**Figure 8. Two bifacial characterisation methods of bifacial with reduced footprint, tested by Eternalsun Spire. The single-side setup is commercially available and already installed around the world**

is seen to offer a very good uniformity of the temperature across the module. The IEC standard recommends this spatial uniformity across the module to be below 2°C. The tool exceeds this requirement as it offers temperature uniformity below 1°C, for all temperatures from 10°C to 85°C.

## Bifacial benefits and guidelines for low-risk (high-accuracy) predictions

Bifaciality is described as the ratio between power generation of the rear side over the front side when both are under one sun illumination. Whereas bifacial PERC+ cells, as introduced by ISFH [5] hold a 80% bifaciality limit, the heterojunction (SHJ) cell concept has inherent bifaciality (about 95%) thanks to its symmetrical structure, as shown in Figure 7.

Bifaciality of cells and modules may be seen as a straightforward gain offering up to 30% higher energy output due to rear-side albedo and due to opportunities of exploiting new system configurations. An example of the latter is vertical east-west-oriented installations that minimise soiling losses and maximise complementary (agricultural) land usage. A study by Fraunhofer ISE [6] on such a vertical installation has shown that the 20% higher bifaciality of heterojunction modules, compared to PERC, gives them a price margin of 20 or 30% (for a levelised cost of electricity (LCOE) of €0.04 and €0.06/kWh respectively).

To accentuate this energy yield gain, the International Electrotechnical Commission (IEC), in charge of the standards for testing PV modules, has decided to label the performance of bifacial PV modules under three situations. First, under 1,000W/m² on the front side and 0 W/m² irradiating the rear side, secondly, with 1,000W/m2 front and 100 W/m² rear simultaneously, and finally, 1,000W/m² and 200 W/m². This standard is labelled IEC 60904-1-2.

Additionally, the standard also describes two indoor experimental manners of testing the performance of the three situations described above. These two test methods are the double-side method and the single-side method.

The double-side method uses two light sources, which are set at the irradiance levels described in the three situations. On the other hand, the single-side method irradiates both front and rear side separately and afterwards the front side at a higher irradiance, thus compensating for the missing rear irradiance. Note that both methods are approved by IEC for R&D test and certification purposes of bifacial PV modules since they yield the same performance results.

Although it might appear that the double-side method is more realistic, it actually adds complexity to the measurement compared to the single-side

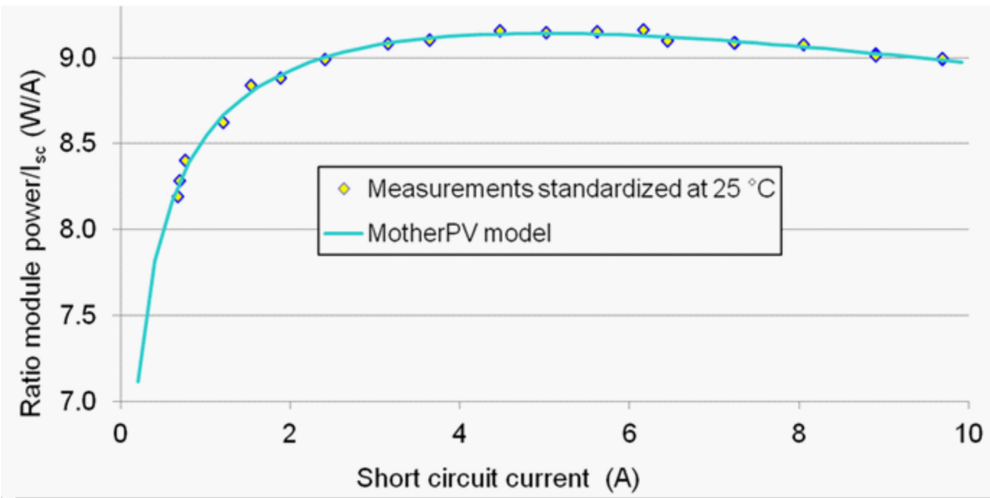


**Figure 9. Mother-PV method: measurement and modelling of the ratio of $P_{MAX}/I_{sc}$ versus $I_{sc}$ (at 25°C). Plotted against the short circuit current $I_{sc}$ that serves as a self-reference for irradiance**

method. This is because there are uneven reflections between both light sources, illustrated by green arrows in Figure 8 (top). Note that one of the requests of the IEC 60904-1-2 norm is that there is less than <3W/m2 of reflection, which means 0.3% of 1 sun irradiance. This can be achieved in the single-side method using a hollow chamber with an anti-reflective coating, which reduces reflections to <3 W/m2, as proven and tested by Eternalsun Spire on its Temperature Controlled Laboratory Flasher (TCLF) on the nine locations described by IEC 60904-1-2 and indicated in Figure 6.

To add proof to the single-side bifacial PV testing method, CEA-INES has applied an in-house developed methodology, labelled 'Mother-PV' (**M**eteorogical, **O**ptical and **T**hermal **H**istory for the **E**nergy **R**ating of **P**hoto**V**oltaics) [7,8].

This method measures module performance at different levels of total irradiance around 1,000 W/m2, in this case applied on both sides of a bifacial module, to model the performance at any total (front+back) irradiance level.

The main equation of the methodology is:

$$P_{MAX} = I_{sc} \cdot ( A + B.I_{sc} + C.I_{sc}^2 + D.\ln(I_{sc}) + E.\ln^2(I_{sc}) )$$

where A, B, C, D and E are the fit parameters of the model.

In conclusion, after applying the method to four different bifacial module types, we found that for a fixed value of the total Isc , bifacial modules behave similar if current is generated on the front- or backside, so without any parasitic or synergetic effects [9].

This conclusion justifies single-sided characterisation of bifacial modules as also proposed in the IEC TS 60904-1-2 test standard, published in March 2019.

## Resilience to potential-induced module degradation

Potential-induced degradation is one of the show-stoppers that has been encountered over the last decade of PV plant operation. The problem, basically already reported back in 1978 by JPL [10], emerged in around 2010 due to the increasingly high operating voltage of the modules far above initial values of 600V. It was also aggravated by the increasing popularity, notably in Europe, of more cost-effective transformerless inverters. From a physics perspective, PID stems

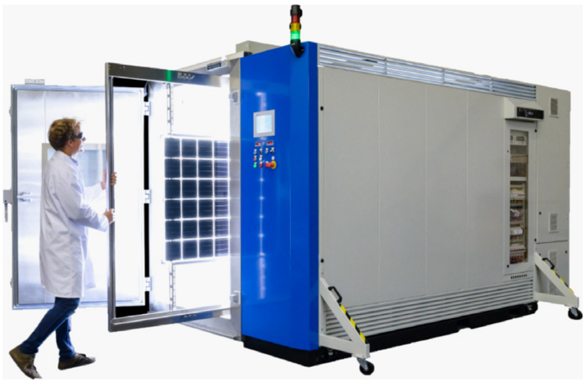

**Figure 10. Climate Chamber Solar Simulator (CCSS), capable of performing accelerated temperature, irradiance and humidity test on modules of different PV technologies**

from the voltage differential between the grounded module frame and the photovoltaic cells near the negative pole of the system using such a transformerless inverter that does not allow grounding.

This voltage difference drives mobile sodium ions from the glass to the cells that are accumulated at either the cell junction, causing PID of the shunting type (PID-s), degrading FF and Rsh. When these sodium ions accumulate in the anti-reflection / passivation layer they cause PID of the polarisation type (PID-p), degrading $I_{sc}$ and $V_{oc}$.

For bifacial modules with glass on the front and rear side the PID problem may concern both the front and backside of the cells. For monofacial PERC cells the PID problem may have been solved for the frontside but once the PERC cells become bifacial their backside, notably the AlOx/SiNx dieletric passivation layer, may become the weak spot as has been recently demonstrated by CSP Halle [11] or SERIS Singapore [12], both showing PID degradation rate from the backside being four times as fast as from the frontside. Whereas the PERC frontside suffers from PID of the shunt type, the backside is degraded by PID of the polarisation type: positive charges are attracted to the AlOX/SiNX stack and eliminate the field effect passivation of the layer stack.

As opposed to the PERC cell structure, the SHJ structure is perfectly symmetrical and instead of dielectric passivation and anti-reflection layers (Al2O3 and SiN) ultra-thin layers of a-Si and ITO are applied. This pays out in a perfect immunity against potential-induced degradation as also reported on commercial HIT modules by Panasonic [13].

## Resilience to light- and temperature-induced module degradation

Light- and elevated temperature-induced degradation (LeTID) is a long-term degradation and regeneration phenomenon that can take years to appear in the field. We have evaluated the LeTID mechanism on commercial PERC modules from a Tier 1 supplier and benchmarked them against the SHJ modules developed at CEA-INES in collaboration with Meyer Burger and 3SUN/ENEL.

We have performed studies on the dynamics of LeTID degradation and regeneration using a dedicated climate chamber with integrated AAA sun simulator as commercially available from Eternalsun Spire, shown in Figure 10. This setup can be used to test the reliability, degradation, regeneration and metastability of cells and modules of any PV technology (such as silicon, thin film or perovskite), controlling irradiance, temperature and humidity while doing in-situ IV measurements.

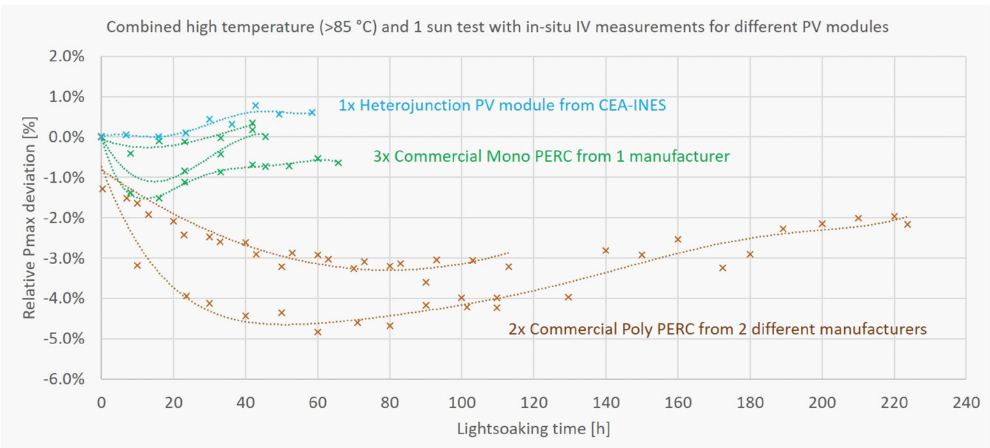


**Figure 11. In-situ LETID testing on PERC modules from different manufacturers, showing up to 5% degradation and subsequent regeneration to different extents; and on a heterojunction PV module from CEA-INES, which does not show any degradation but a regeneration of about 1%**

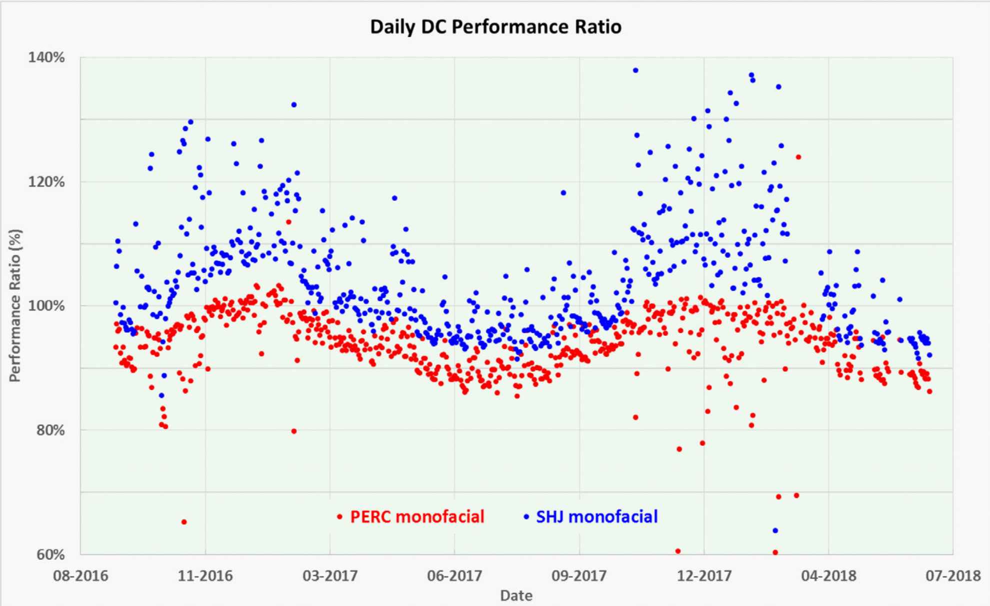


**Figure 12. Outdoor monitoring of the average daily system performance ratio over the years 2016-2018 at the site of CEA-INES in Bourget-du-Lac (France). Monofacial PERC modules in red, monofacial SHJ modules in blue**

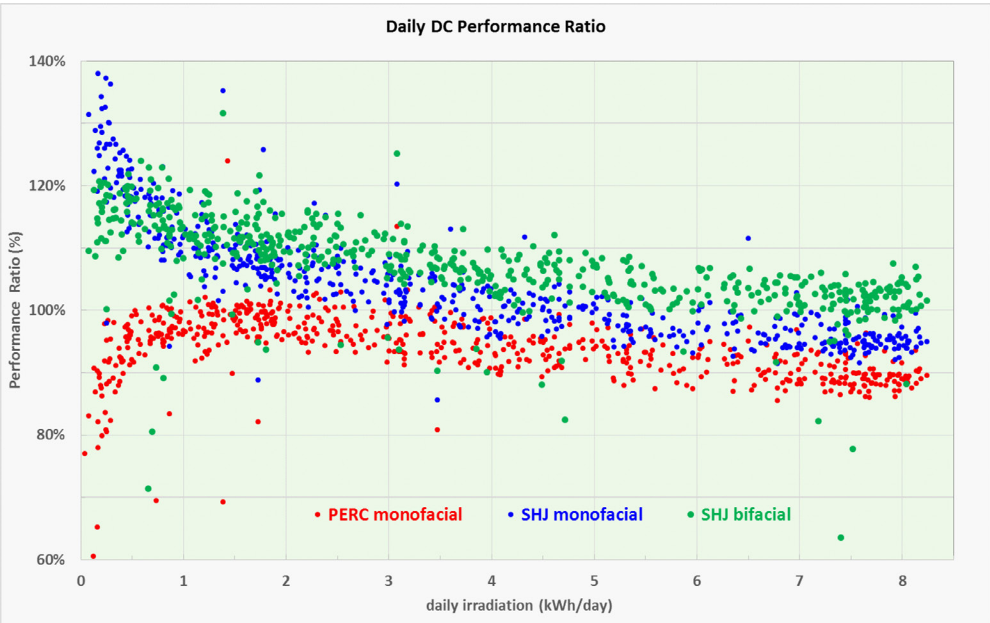


**Figure 13. Outdoor monitoring over 2016-2018 of the average daily performance ratio as a function of daily irradiance. Bifacial SHJ system in green**

The interest of running such in-situ testing in this dedicated climate chamber is clearly motivated by the dynamic character of the LETID mechanism. If the sun simulator is not integrated, then occasional ex-situ IV measurements are needed, and the major phases of the mechanism, such as the maximum degradation and the onset of regeneration, may easily be missed. The results of testing five different commercially available PERC modules are shown in Figure 11.

In a similar way these LeTID dynamics have been tested on SHJ modules, as also presented in Figure 11. It can be observed that the LeTID test conditions do not provoke a degradation on the SHJ modules but in fact an effective increase of a few percent in module power. The improvement appears strictly related to an increase in $V_{oc}$, which resembles the reported increase of $V_{oc}$ by light soaking at moderate temperature (32°C) of SHJ modules [14, 15]. This in contrast to the LeTID degradation of PERC modules, which appears as a combined effect of degradation in $V_{oc}$, $I_{sc}$ and FF.

The inherent resilience of the SHJ technology against LeTID is attributed to favourable hydrogen kinetics (lower saturation and effusion) due to a cell process temperature that is considerably lower (<200°C) compared to PERC (around 800°C) as well as to a-Si:H passivation layers that are much thinner (< 10 nm) compared to the passivation layers of PERC technology. Moreover, the absence of boron in n-type wafer-based SHJ cells helps to eliminate the $V_{oc}$ degradation upon light exposure.

## How this all effects the yield in outdoor operation

Figure 12 shows the results of outdoor performance monitoring over a period of two years at the site of CEA-INES in Bourget-du-Lac (see Figure 14) for a system of 10 commercial PERC modules and another system of 10 SHJ modules manufactured on the cell and module pilot lines at CEA-INES.

The graph shows the usual seasonal effect, with a higher performance ratio in winter due to lower than STC temperatures. As the temperature coefficient of SHJ modules is lower than that of PERC modules, the seasonal temperature cannot explain the larger performance offset between SHJ and PERC during winter. To better compare these monitoring data with the outdoor data in Figure 4 we have replotted the results as function of the daily irradiance (in kWh/day). Also we have added a bifacial SHJ module (in green) to the graph.

The results in Figure 13 show that the monofacial SHJ module has on average an 8% higher Performance Ratio than its monofacial PERC counterpart. For the bifacial SHJ module this difference goes up to 14%. Figure 13 also shows the better performance of SHJ modules at low irradiance levels. This then explains the higher offset, observed in figure 12, between PERC and SHJ modules during winter, with more frequent occurrence of low irradiance.

These favourable results for SHJ modules should also be set in the perspective of the annual module degradation rates that have been reported by NREL [16] for heterojunction modules that had been fielded for over 10 years. They reported an annual (linearised) decline of 0.67 ± 0.18% per year, which is statistically similar to an average c-Si based system. They concluded that the degradation was dominated by a decrease in $V_{oc}$ due to an increase of recombination in the cells along with a decrease by a factor of two in minority carrier lifetime.

A similar conclusion was drawn by a two-year outdoor evaluation by TUV Rheinland of SHJ modules in four different climates [17].

## Conclusions/outlook

Accelerated indoor tests using in-situ IV characterisation of silicon heterojunction modules showed them to be insensitive to LeTID degradation, as opposed to the commercial PERC modules tested under similar conditions. Similarly no signs of PID degradation were detected for the SHJ modules. The use of a single long-pulse flash is critical for the accurate IV measurement of heterojunction modules. With respect to low-light performance and temperature stability, SHJ modules were found to outperform PERC modules. Finally, a comparison of monofacial SHJ and PERC modules during extended outdoor monitoring showed the SHJ modules to have a superior performance ratio. ■

**Figure 14. A partial view of the CEA-INES testsite in Bourget-du-Lac**


## Acknowledgements

Meyer Burger and 3SUN/ENEL are gratefully acknowledged for joint development efforts, technical discussions and support. The results reported here have been obtained through the collaborative effort of all members of the heterojunction pilot line and PV module platform at CEA-INES. Special thanks to Hervé Colin for managing the outdoor monitoring site at CEA-INES.



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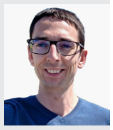
Stefan Roest is co-founder and CTO of Eternalsun Spire, which contributes to the development and growth of the solar industry by enabling the highest accuracy measurements of the efficiency and reliability of PV modules. Stefan Roest is an active member within the IEC TC82 WG2 and is involved in several testing related project teams of PV modules of different technologies.

Lionel Sicot received his Ph.D. in 1999 in physics of materials from Orsay University (France) for a thesis on organic solar cells. From 2000 to 2007, he worked in this field in the Organic Components Lab at CEA. In 2007, he joined the PV systems lab at CEA-INES and since 2017 has been working on the industrialisation of bifacial heterojunction technology.



Benjamin Commault graduated as a materials engineer from Polytech Nantes in 2011, and since then has been working as a research engineer in PV at the French Institute for Solar Energy (INES). At CEA-INES he has gained more than two years' experience in the development and production of heterojunction solar cells, and since 2014 he has been working on the R&D of c-Si PV modules.

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