

## 1. INTRODUCTION

Bifacial solar modules use direct and reflective sunlight to produce energy from the front and rear surfaces of the module. As a result, they achieve a higher yield. Until now, bifacial technology, which was developed in the 1970s, has had only a small market share due to high production costs. In September 2015, the Institute for Solar Energy Research Hamelin (ISFH) and SolarWorld AG presented an innovative industrial manufacturing process for the economically viable bifacial cell and module applied science.<sup>[1]</sup>

The process is based on the technology of high-performance PERC cells (passivated emitter and rear cell), which SolarWorld has successfully implemented in series production.<sup>[2]</sup> With the development of the new bifacial glass-glass product *Sunmodule Bisun*,<sup>[3]</sup> SolarWorld has profited from this technological expertise and experience in series production. The advantages for energy yield and performance technology are discussed in depth throughout this paper.

## 2. HISTORY

The idea for developing bifacial modules emerged at the end of the 20th century. In the early 1970s, Cuevas et al. reported an increase in power output of 50 percent by using special light-concentrated systems and solar panels with bifacial solar cells.<sup>[4]</sup> Bifacial module technology has remained as the exception in the PV market. Most current bifacial developments are based on complex solar cell architectures on the basis of n-type silicon substrates<sup>[5,6,7]</sup> or heterojunction solar cells.<sup>[8,9]</sup> These result in high production costs due to their vast consumption of expensive silver paste. As a result, the market share of bifacial modules has remained very low. For 2015 the forecast was only 5 percent.<sup>[11]</sup>

## 3. CELL

The bifacial solar cell is a further development of the high-performance PERC cell. SolarWorld has made great strides in the development of PERC technology. A new world record of 22.04 percent<sup>[10]</sup> cell efficiency using industrial p-type Cz-silicon recently demonstrated this achievement. Figure 1 shows a schematic diagram of a PERC cell and a bifacial solar cell. In contrast to the PERC cell, the bifacial solar cell has an opening in the screen-printed rear contact to allow light to reach the active region of the cell from the back. The full-area aluminum printing of the PERC cell has been replaced with an optimized grid, similar to the front contact;

the thickness of the rear passivated layer was reduced to increase light transmittance.

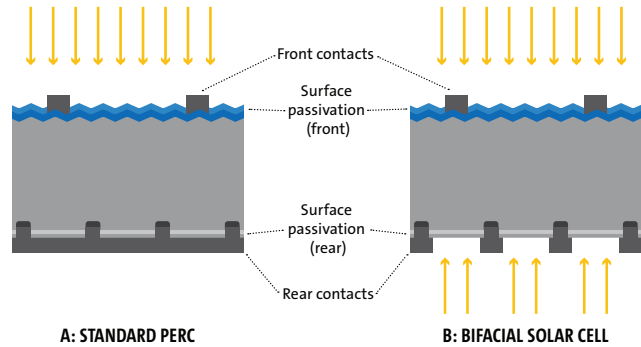


FIGURE 1: Schematic cross-section of PERC structure (A) and a bifacial solar cell (B)

## 4. MODULE

Bifacial solar cells have the advantage of producing more energy by using reflective incidental light from the rear along with light from the front of the module. With the transparent rear sides, glass-glass modules therefore provide the ideal module technology for bifacial solar cells. A second glass plate on the rear of the module allows reflected sunlight to reach the cells from the back. In this way, individual modules generate higher yields. Embedding the cells in a glass composite protects them from environmental and mechanical influences. High durability and minimal degradation ensure a maximum service life. Because SolarWorld is among the manufacturers that produce glass-glass modules at an industrial scale, the new bifacial product profits from a mature technological process.

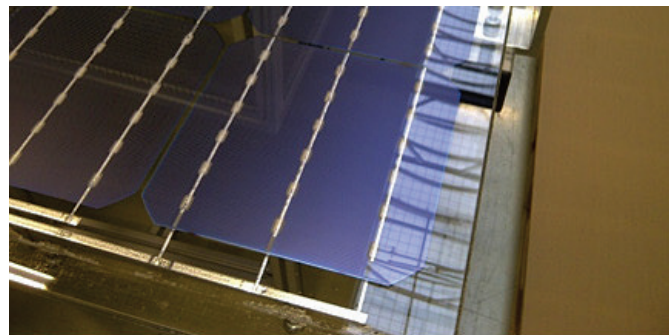


FIGURE 2: Rear side of a bifacial module in production

There is a new relevant parameter for bifacial solar modules in addition to the front side maximum power at standard test conditions ( $P_{mpp,front}$ ): the bifaciality B, which refers to the ratio of the front to the rear power measured under standard test conditions (STC).

$$B = \frac{P_{mpp, rear}}{P_{mpp, front}}$$

The first generation of bifacial SolarWorld modules has already achieved a bifaciality of over 65 percent. Further improvements are expected as a result of ongoing solar cell development. Dullweber et al. presented a bifaciality of up to 80 percent for five-busbar modules.<sup>[10]</sup>

## 5. SIMULATION OF THE INFLUENCES ON THE ENERGY YIELD

The transparent and active rear side of bifacial modules enables additional energy production. The “energy boost” of a bifacial PV system describes the increase in specific energy yield (kWh/kWp) of the bifacial module compared with a monofacial module in the same system.<sup>[12]</sup> Direct or diffused light is reflected from the ground and a portion is scattered to the rear of the module (Figure 3). The amount of light that reaches the rear side largely depends on two factors: the albedo of the ground and the installation height of the module.

### A. ALBEDO – MEASUREMENT AND TEST SETUP

The albedo describes the reflectivity of a non-luminous surface—it is determined by the ratio between the light reflected from the surface and the incidental radiation.

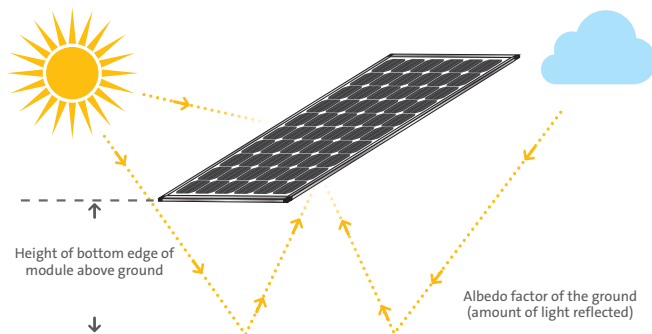


FIGURE 3: Schematic of a system using bifacial modules

To measure the relevant portion of the wavelength of the incoming and reflected light, a mini module with a PERC cell was selected as the test bed. The short circuit current of the module was measured twice—once with the module exposed to the sky and the second time with the module exposed to the ground.

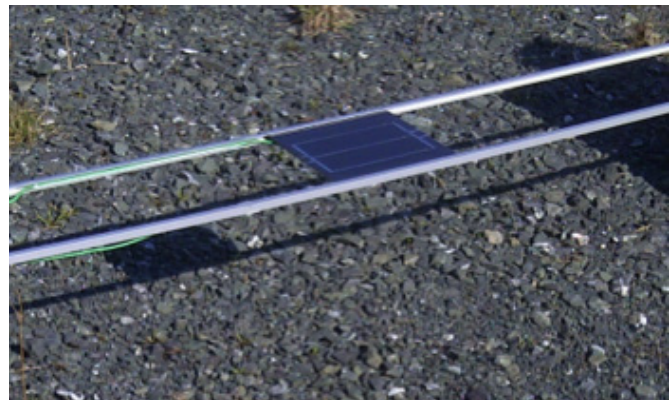


FIGURE 4: Albedo measurement test setup with laminated bifacial solar cell. The albedo is calculated as the ration of short circuit current  $I_{sc}$  exposed to the sky and  $I_{sc}$  exposed to the ground

Measured albedo values of common ground surfaces are listed in Table 1. For a green field, an albedo of 23 percent was measured. For concrete (>10 years weathered), an albedo of 16 percent was measured. Adding white paint (Figure 5) boosts the albedo of concrete to 62 percent. Albedo values of over 80 percent are possible depending on the thickness and type of paint of the ground surface. Additional roofing materials are listed below (Figure 5). Surprisingly, the value for white gravel is only 27 percent—the open-pored structure causes a large amount of the reflected light to be lost within the voids. Other flat standard construction materials like roofing foil (membrane) or sheet metal have higher albedos of up to 50 or 60 percent. The highest albedo measured is of special foils/membranes which were specifically developed for solar applications.

SURFACE TYPE	ALBEDO
Green field (Grass)	23%
Concrete	16%
White painted concrete	60-80%
White gravel	27%
White roofing metal	56%
Light grey roofing foil	62%
White roofing foil (for solar applications)	> 80%

TABLE 1: Albedo values of certain ground surfaces measured with test set-up according to Figure 4



FIGURE 5: Ground surface albedo test: 1) white painted concrete 2) white gravel

**B. INSTALLATION HEIGHT OF THE MODULE**

The installation height of the module is the second main influence on the energy yield of a bifacial module. Figure 6 shows simulated data for the additional energy yield (energy boost) for a landscape-mounted bifacial module (one module per row, 30 degree pitch, south orientation, 2.5 meter row pitch, 80 percent albedo) with variable installation height.

The higher the installation height of the module, the higher the additional energy yield will be of the bifacial PV module. However, Figure 6 shows the saturation curve reaching its inflection point at an installation height of about 0.5 meters. Beyond this point, any additional energy yield only increases slightly.

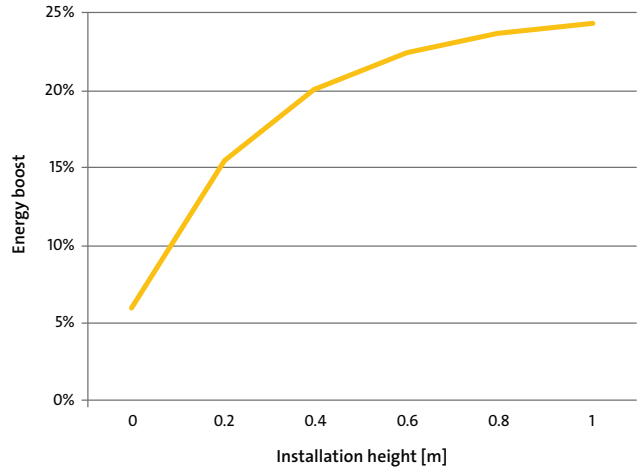


FIGURE 6: Energy boost of a bifacial PV system with landscape mounted module, south oriented, 30 degree pitch and a row pitch of 2.5 meters, 80 percent albedo

**6. CONCLUSION**

Researchers and module manufacturers have been developing bifacial cell and module technology for decades. The new process for manufacturing bifacial solar cells based on the PERC technology from SolarWorld makes the bifacial cell technology more cost-effective and suitable for industrial production. The bifacial module of this new generation, the Sunmodule Bisun from SolarWorld, is available as a glass-glass module with 60 bifacial cells or a glass/clear backsheet module with 72 bifacial cells generating power on both sides and additional energy yield. The size of this increase depends mainly on the reflective behavior of the surface underneath the module and the installation height of the solar power system. An optimal combination of reflective surface and the highest possible system height makes it possible to achieve an additional energy yield of up to 25 percent. In the field, the Sunmodule Bisun is best suited for flat roofs and ground-mounted systems where light is reflected from the ground. The increased energy yield and long durability of bifacial glass-glass modules contribute to a further reduction in the cost of energy production for all applications.



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