bifiPV2022 status and future: Entering the bifacial nPV era

Radovan Kopecek & Joris Libal, ISC Konstanz, Germany

Abstract

After several years of technological developments, measurement and quality standard specifications, and bifaciality implementations in energy yield simulation programs, bifacial PV has become reliable and will shortly become accepted as a valuable commodity. Since 2020, bifacial passivated emitter and rear cell (PERC) technology has been king of the energy markets, and, in combination with simple tracking systems (e.g. horizontal single-axis tracking – HSAT), the lowest electricity costs have been achieved. Because PERC is reaching its limit in terms of efficiency, and n-type technology is gaining momentum, in the future n-type PV (nPV) will replace PERC technology as the workhorse of the PV electricity market. This paper describes why, and most likely when, this will happen and which n-type technologies will be leading the pack in the race to bring electricity costs well below €0.01/kWh.

Introduction

We did it! Mid-March 2022 saw the installation of a cumulated capacity of 1TWp of PV system power worldwide [1]. In 2021 the total installations added up to about 180GWp, even though PV was currently in a poly-Si supply shortage crisis and, in consequence, the market was driven by availability and no longer by demand. In 2022, total installations of about 230GWp [2] are expected, and in the coming years, unlike what the International Energy Agency (IEA) or BENEF are predicting, an exponential increase will be necessary in order to reach the ambitious goals regarding CO_2 reduction. In the authors' opinion, such an exponential growth is not only necessary but also realistically possible, as the global world comes to understand the technological and economic potential of PV.

Fig. 1 depicts IEA's forecast of GW added per year compared with the actual figures. For more than 15 years, the predictions have been wrong, and the yearly installed PV technology power has always been underestimated. The increased growth follows a simple rule, identified by Pierre Verlinden some years ago: every third year, production doubles, which has been the case during the last 15 years. The authors are sure that the same trend will be true in future years as well, before saturation is reached at several TW. This means that from 2028 onwards, PV capacity

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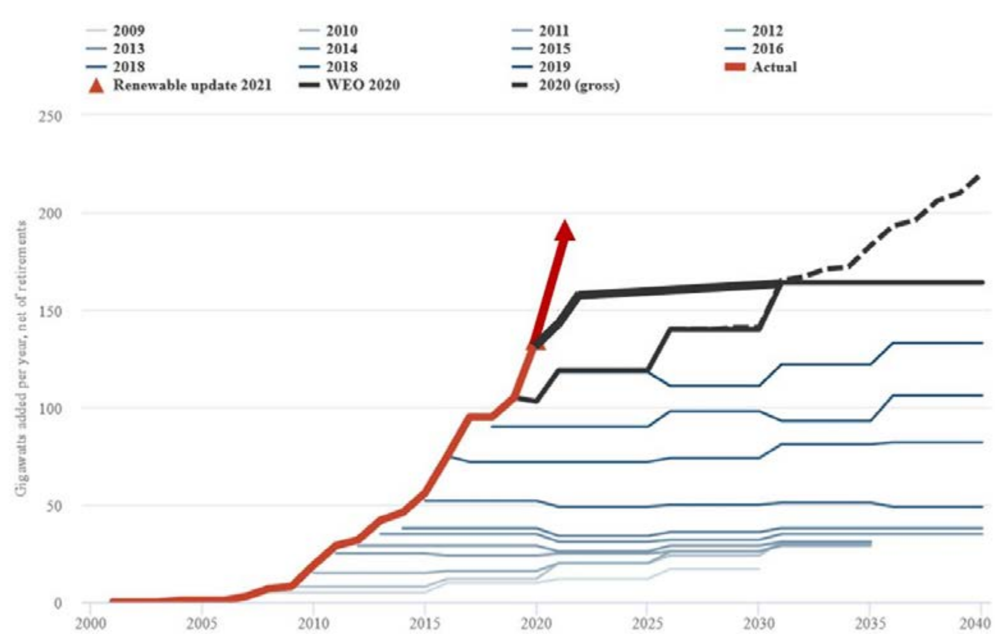


Figure 1. IEA's forecast of GW added per year versus reality (adapted from "IEA forecasts" [3]).

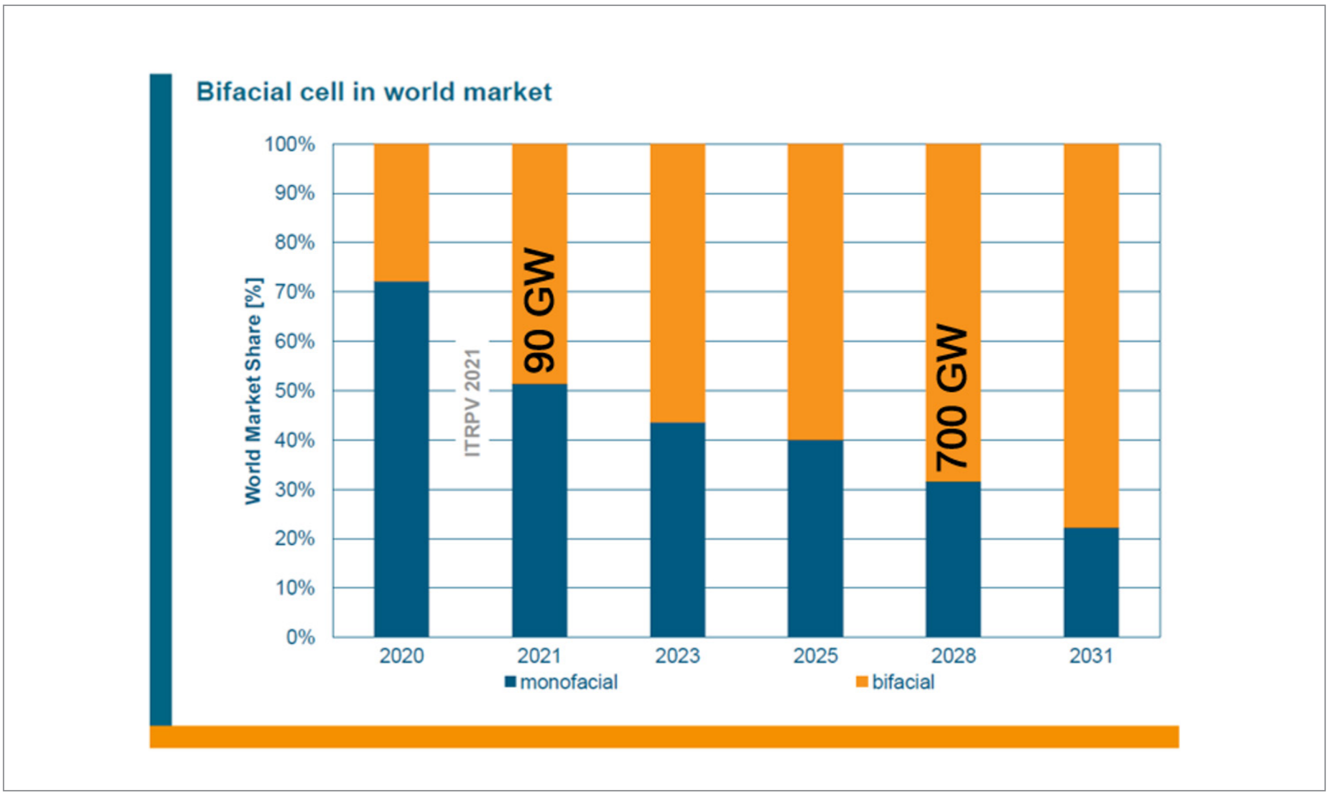


Figure 2. ITRPV 2021's forecast of the market share of bifacial cell technology.

is likely to reach 1TWp/year, with the major share being picked up by bifacial technology. Fig. 2 shows the forecast of the International Technology Roadmap for PV (ITRPV) of the market share of bifacial technology. Already 90GW bifacial cells had been produced in 2021, whereas 700GW are expected in 2028.

By 2030 there will be hardly any monofacial cell technology remaining on the market, almost entirely thereafter being replaced by its bifacial rivals. The technologies that will dominate at that time are the topic of discussion in the following section.

Status of bifacial technology

Bifacial PV's beginnings can be traced back to the first bifacial PV system at the MWp level incorporating n-type nPERT technology in a fixed-tilt configuration, such as the one located in Japan in 2013 using EarthON nPERT technology [4] (see Fig. 3). Bifacial nPERT was much more expensive at that time, mainly because the cost of n-type wafers was more than 30% higher than the cost of p-type wafers.

MegaCell, in 2015, started BiSoN (**bi**facial **so**lar cell on **n**-type) cell and module production. Using BiSoN modules, MegaCell set up a 2.5MWp [5] fixed tilt system, and ENEL a 1.75MWp [6] HSAT system, both in Chile in 2016. The year 2016 was, however, also the time when bifacial passivated emitter and rear cell (PERC) technology entered the market and offered a more cost-effective alternative for bifacial modules. While this slowed down the growth of n-type cell technologies, it helped a lot in pushing bifacial PV at that time. Since 2018, large HSAT bifacial PERC systems have begun to enter the market very quickly, and are monopolizing the bifacial PV market today. One of the largest of these is the planned 1.3GW HSAT bifacial PERC system in Karapinar (Turkey), which will be finalized in 2022 [7].

How did bifacial PV become standard? When the bifiPV workshops began in 2012 in Konstanz, there were still many challenges to overcome, as the benefits of bifaciality were not commonly recognized by the PV community. The developments considered to be the most important to make bifaciality bankable and sustainable were:

1. Implementation of bankable energy simulation programs.
2. Development of bifacial PERC technology.
3. Use of white reflectors between cells.
4. Combination of HSAT with bifacial modules.

Standards are important as well, but are not being used by many for measuring modules, and bifaciality is more of a priority. The authors believe that this will change when bifacial modules achieve the higher bifaciality of PERC modules, with bifacial factors between 0.6 and 0.7. Fig. 4(a) illustrates the white ceramic reflector on the rear side of the bifacial PERC module, which increases the front-side power of the module (and slightly reduces the bifacial factor). The final production stage of frameless double-glass modules is shown in Fig. 4(b).

On the one hand, PERC cell technology is now approaching its efficiency limit, while on the other, cell technologies based on n-type Si material offer the potential for not only higher efficiencies and

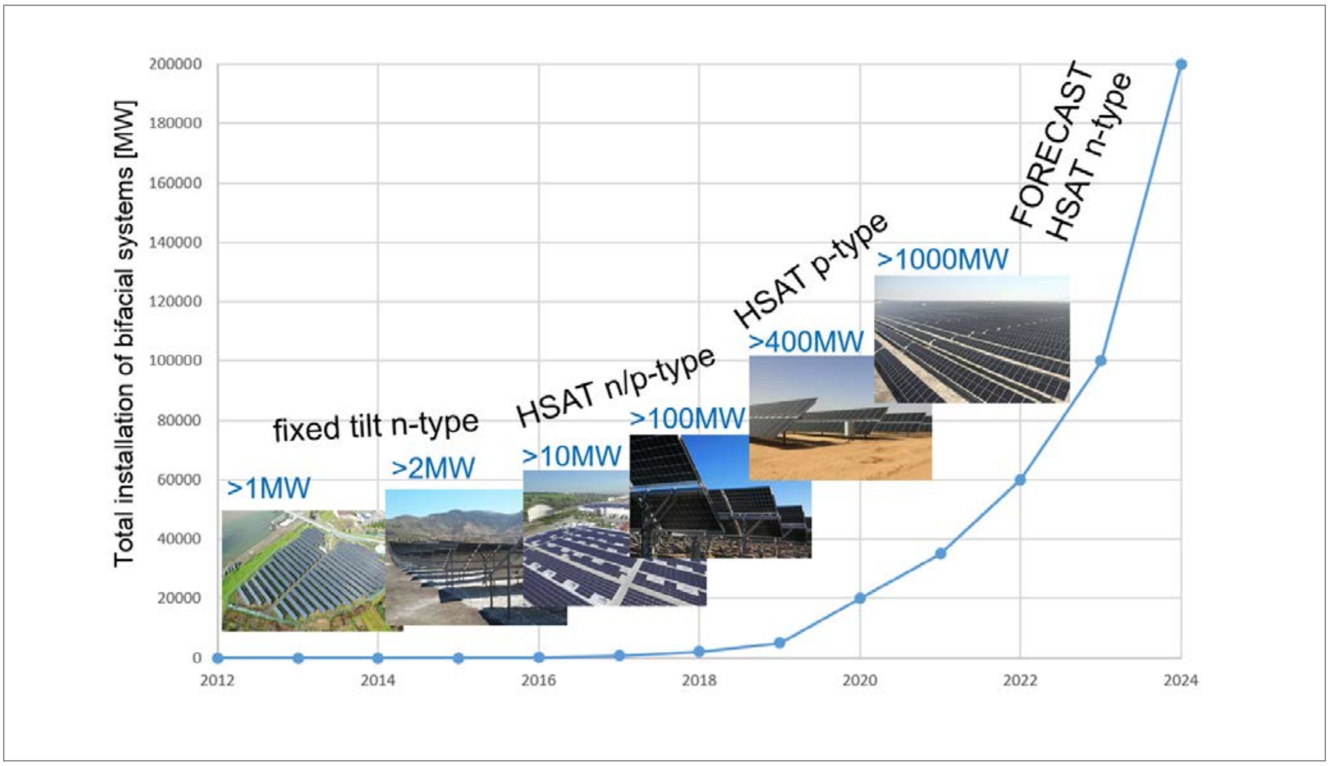


Figure 3. Cumulated bifacial PV system power over the years and the most prominent technologies in use at the time.

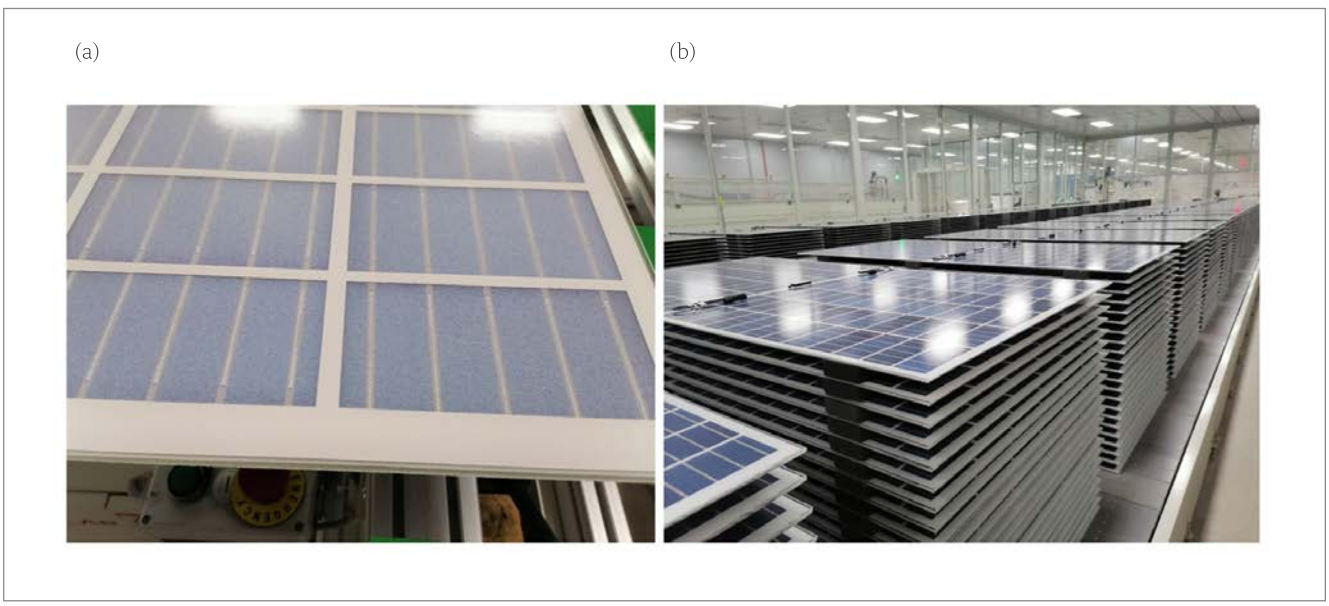
lower temperature coefficients, but also lower yearly degradation rates and higher bifaciality. For these reasons, the authors are convinced that the beginning of a bifacial n-type PV (nPV) era is imminent.

Upcoming solar cell technologies

The high-efficiency potential of all the important solar cell technologies on the market has already been reported in the previous edition of *Photovoltaics International* [8]. PERC will end up with efficiencies of between 23% and 24% in production, whereas n-type technologies will soon exceed 24%, and even 25% in the future.

Table 1 summarizes the available modules on the market, where among the top ten, nine are n-type modules consisting of interdigitated back contact (IBC), heterojunction technology (HJT) and tunnel oxide passivated contact (TOPCon) solar cells. Whereas PERC technology modules deliver efficiencies between 21 and 22%, most n-type technologies are starting to exceed 22%. They also have a lower temperature coefficient as well as a higher bifacial factor. Furthermore, if processed correctly, n-type technologies show lower degradation as well.

In the following discussion, not only will the efficiency and other device advantages and



Credit: Kalyon.

Figure 4. (a) Rear side of a bifacial PERC module before lamination. (b) Curing of glued junction boxes of frameless modules.

Most Efficient Solar Panels 2022 *				V3.2 - Mar 2022
Manufacturer	**Model**	**Max power (W)**	**Cell Type**	**Efficiency**
SUNPOWER	Maxeon 6	440W	N-type **IBC**	22.8 %
CanadianSolar	CS6R-MS	440W	N-type **HJT** Half-cut	22.5 %
LG	Neon R	405W	N-type **IBC**	22.3 %
Panasonic	EverVolt H	410W	N-type **HJT** Half-cut	22.2 %
Jinko Solar	Tiger NEO	480W	N-Type TOPcon Half-cut	22.2 %
SPIC	Andromeda 2.0	435W	N-type **IBC** Half-cut	22.1 %
REC Solar	Alpha Pure	405W	N-type **HJT** Half-cut	21.9 %
Trinasolar	Vertex S +	425W	N-Type Mono Half-cut	21.9 %
MEYER BURGER	White	400W	N-type **HJT** Half-cut	21.7%
JA SOLAR	Deep Blue 3.0 light	420W	P-Type Mono Half-cut	21.5 %

Table 1. Highest-efficiency solar panels available on the market in March 2022 [9].

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drawbacks be examined, but also the maturity of each technology and its production costs (cost of ownership – COO). The COO of n-type technologies is edging closer to that of PERC, but is not yet overtaking it for several reasons.

PERC is the current industry standard but is getting close to its efficiency limits at the module level, demonstrating between 21% and 22% (Fig. 5). *TOPCon* is considered to be the 'next big thing', as it is a natural upgrade of PERC technology using n-type wafers, passivating contacts (poly(n^+)-Si) on the rear, and B diffusion on the front. Since it is an evolutionary upgrade of PERC, it can benefit from the existing process equipment and material supply chain. In addition, the module technology does not have to be adapted.

The next step would then be to include passivating contacts using poly-(p^+)Si as well, and adapt it in a back-contact technology. *IBC* technology offers the highest efficiency combined with perfect aesthetics and is a very simple and effective module technology. A negative gap with overlapping IBC cells is extremely easy to realize when both contacts of each polarity are on the rear.

HJT is a revolutionary successor with a simple low-temperature cell process. However, it incurs high production costs, as it is extremely sensitive towards wafer quality and impurities within the production process, as well as demanding a relatively high consumption of costly low-temperature Ag pastes. In addition, the module technology is not standard, because the solar cells cannot be exposed to high temperatures during soldering and lamination. A further hurdle caused by HJT requiring scarce materials (such as Indium and Bismuth) will become evident when PV enters the 1TWp/year era soon.

A rudimentary assessment of all technologies is presented in Fig. 6(a), in which several categories have been identified. The highest score (largest area of the polygon) is attributed to PERC and TOPCon; however, in the near future IBC – which so far has already been realized by a few Tier 1 manufacturers – will too see more benefits.

The major advantages of HJT are the low temperature coefficient and the high bifaciality. In other categories, however, HJT has huge drawbacks, and that is why it is commonly believed that this

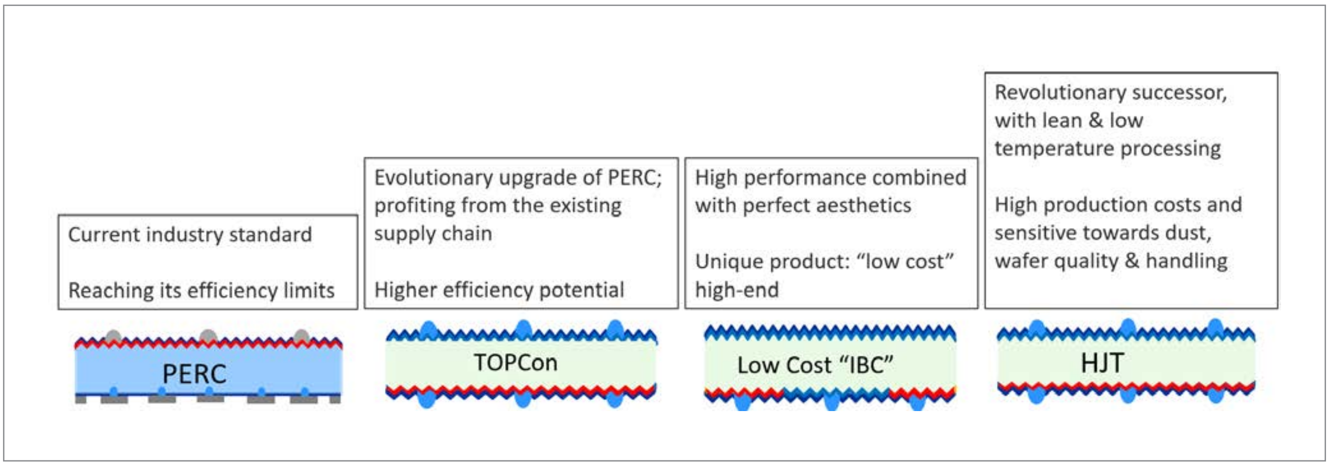

Figure 5. Dominating c-Si cell technologies at the present time and those of the future.

technology will not play a major role in the future. TOPCon has the brightest future, as forecasted by PVInfolink in Fig. 6(b), and will be PV's next workhorse. Nevertheless, it is thought that, after 2025, IBC technologies will also enter the PV market, and prior to 2030 will play a major role, as they have the highest efficiency potential and will be the next upgrade step from TOPCon. Indeed, they are already being introduced, e.g. by LONGi and AIKO, who are currently setting up GW-scale production facilities for IBC technology. Moreover, a French Consortium in collaboration with ISC Konstanz will set up a 5GW production capacity in France built on TOPCon and IBC technology [11].

COO and LCOE

The COO has been very dynamic in recent months, as the cost of poly-Si – and therefore also of the wafer – have increased dramatically. One year ago, the COO for a PERC solar cell was of the order of

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US$0.1/Wp, whereas it has increased to around US$0.17/Wp at the moment. These calculations are based on prices of US$0.96 for a p-type M10 Cz-Si wafer and US$1.05 for an n-type M10 Cz-Si wafer.

Fig. 7(a) shows the cell costs and how dominant the wafer costs are. In the following, since wafer costs are very dynamic, in order to compare different technologies, it makes more sense to look at the relative differences between costs. It can be seen at the module level (Fig. 7(b)) that the difference between PERC and TOPCon is only US$0.026/Wp (only 10% higher), which is very low, as TOPCon

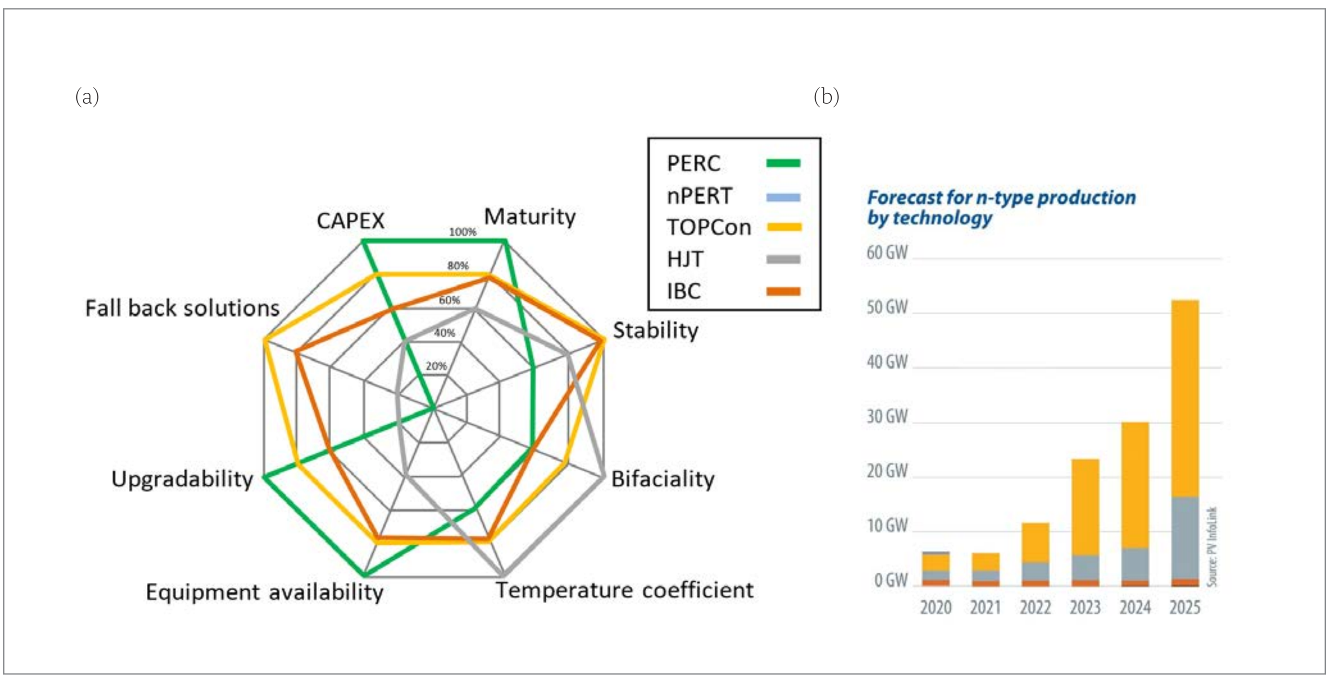

Figure 6. Technology evaluation matrix (a) and forecast for n-type technologies (b) [10].

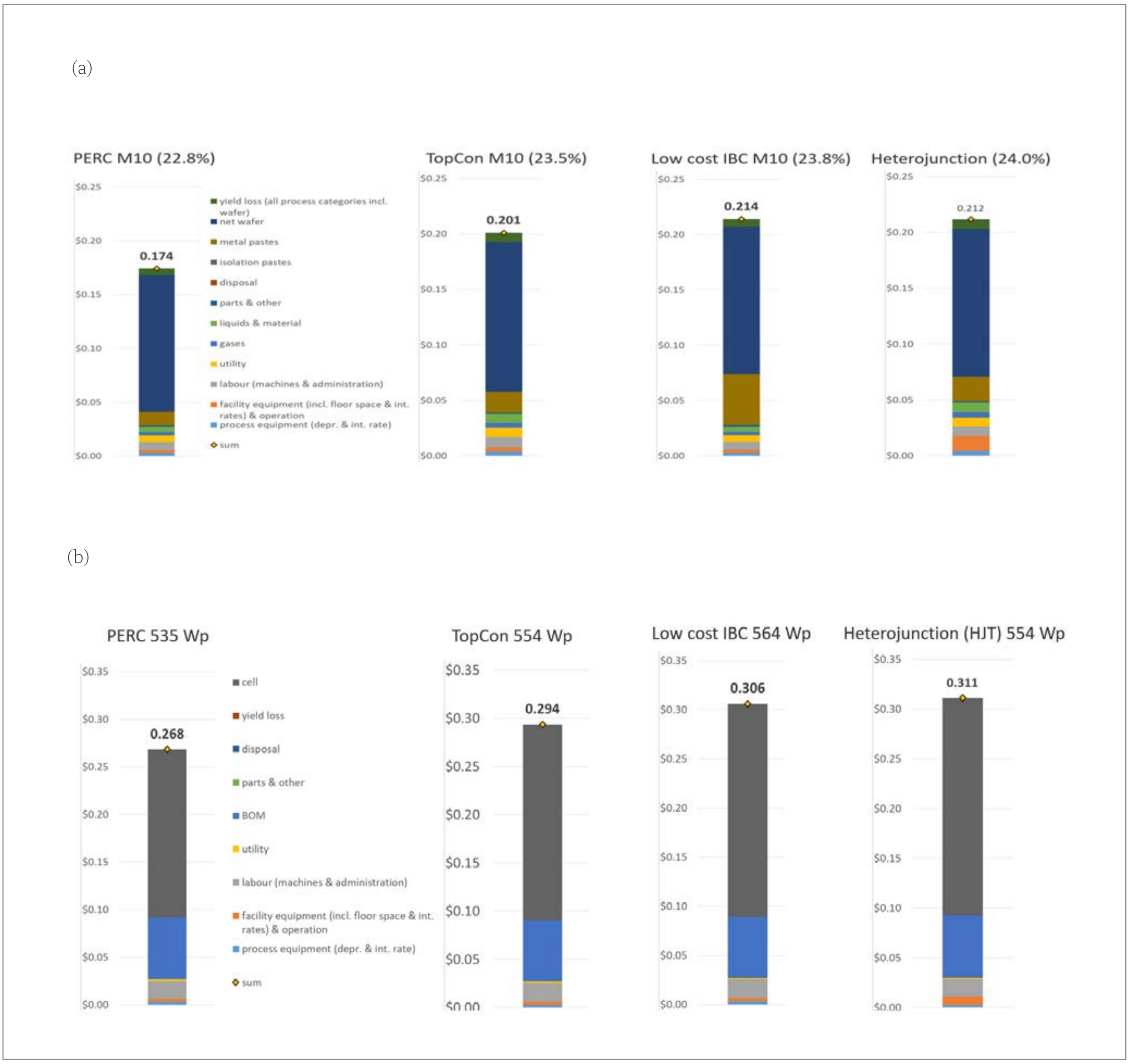

Figure 7. Result of COO calculations for (a) cells and (b) modules for different technologies in the case of a 5GWp/year cell and module factory in a low-cost Asian location (calculations based on current polysilicon and wafer costs).

modules offer many advantages in terms of the levelized cost of electricity (LCOE).

The cost factor between PERC and TOPCon at the module level is only 1.1, and this will eventually decrease even more as a result of the higher efficiency of TOPCon and less silver consumption. It is therefore beyond doubt that the future belongs to bifacial n-type technology, and that the bifacial nPV era is on the horizon. This can be already be seen now on a LCOE level in some cases. Take, for example, a region with a high radiation of 1,830kWh/m^2 (e.g. Malaga in Spain), a high average temperature of 23°C and a high albedo of 30%. Again, it is more interesting to look at differences rather than absolute numbers. It is immediately evident from Fig. 8 that using bifacial modules is beneficial in any scenario, with monofacial PERC showing a higher overall LCOE. The lowest LCOE is achieved by TOPCon technology, which will put even more distance between it and PERC in the future.

It is not surprising that in hot regions, on sites with high albedos, bifacial nPV is already starting to be used in large utility-scale systems, yielding a yearly bifacial energy gain of up to 30% [12]. Jolywood and Risen have set up the largest systems for TOPCon and HJT respectively (Fig. 9). Because of the higher bifacialities, lower temperature coefficients and lower degradations, these systems will most likely demonstrate superior performance – in other words, a higher specific energy yield (kWh/kWp), as it is known in PERC technology parlance. With the beginning of the nPV bifacial era, it is clear that IEC standards for the measurement of bifacial cells and modules will become more important as module producers try to push the power of the rear side as well ('bifi100' or 'bifi200' according to IEC TS 60904-1-2:2019) as a selling point.

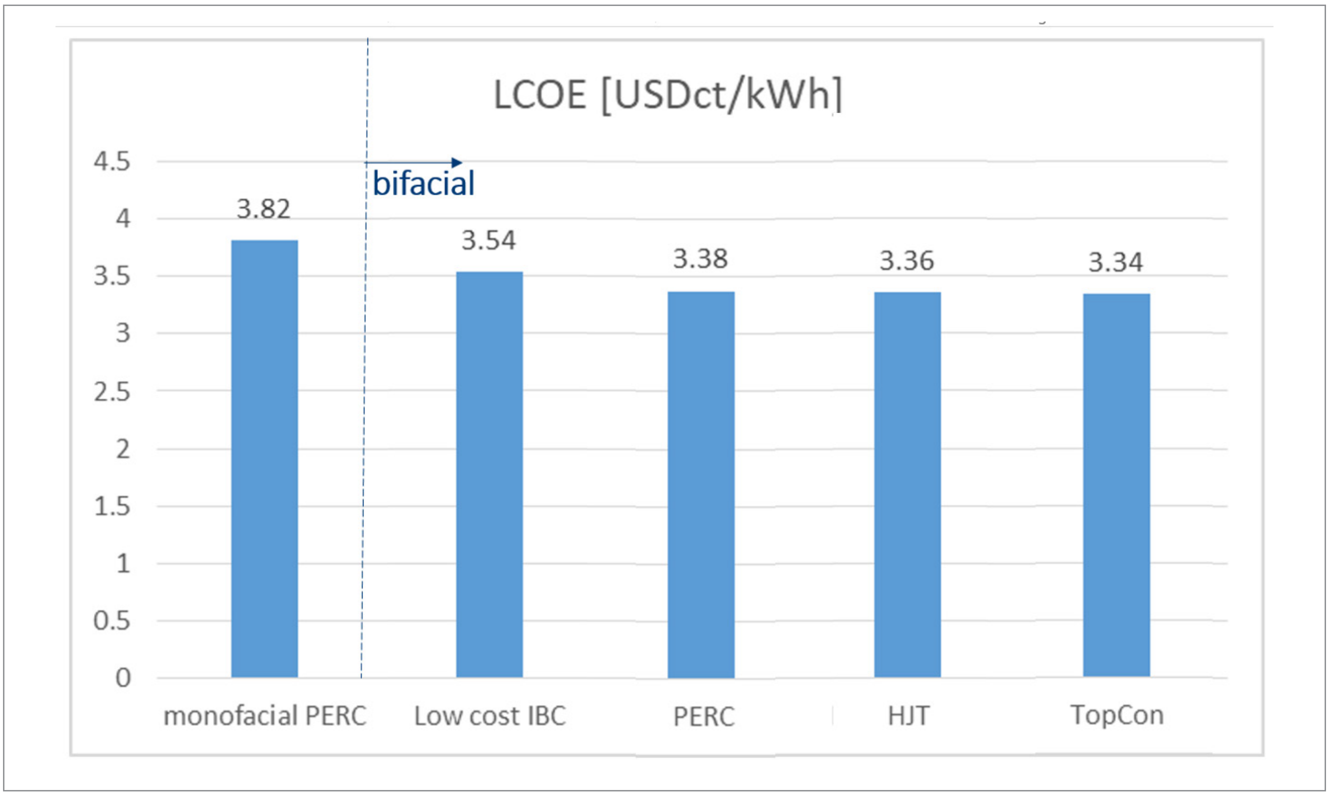

Figure 8. Result of a sample LCOE calculation for Malaga, Spain, for monofacial PERC in comparison to bifacial technologies, based on a discount rate of 5% and a system lifetime of 25 years.

Summary and outlook

With PERC as its mainstream technology, enabling electricity costs below €0.01/kWh, PV has been the king of the energy markets since 2020. To become emperor, however, the following conditions will have to be met:

- Market availability of effective and low-cost storage.
- Reduced PV balance of system costs.
- Increased solar cell and module efficiency.

Satisfying the third requirement above will result in a slight further decrease in costs/Wp, ultimately stabilizing at around €0.15/Wp (module cost).

With PERC getting ever closer to its efficiency limits – around 22% at the module level – n-type crystalline silicon technologies are currently on the upswing, yielding module efficiencies well above 22%. However, it is not only efficiency that matters, but also lower temperature coefficients, lower degradation rates and higher bifaciality. Although n-type technologies still involve higher costs/Wp, they are becoming more and more interesting, even for large utility-scale deployment in hot regions with high albedo, such as the 500MW Ibri II project in Oman; this

Figure 9. Use of TOPCon and HJT modules in bifacial HSAT utility-scale systems: (a) Jolywood in Oman; (b) Risen in China.

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system, comprising bifacial TOPCon modules from Jolywood, demonstrates the beginning of the new 'bifacial nPV era'. Bifacial PV started with n-type, PERC made it standard, and soon n-type technology will take over again.

During the switch from Al-BSF to PERC, the most critical hurdle was the standardization of the process and equipment. At the beginning, there were still many open questions: for example, how to open the dielectrics on the rear side (wet chemically, by lasers, shadowing masks) or how to even fire through the Al paste with lasers (laser-fired contacts, LFC). The other critical process was to select the best passivation technology for the p-type Si rear surface of the cell. As soon as the most effective processes had been selected and the machines developed, the switch was accomplished very quickly.

In the case of TOPCon, the process sequence has already been selected – the only thing now that remains to be standardized is the deposition tool for poly-Si and its doping. Once this is done, then the switch from PERC to TOPCon could be completed within 3–5 years. After that, because of its even higher efficiency potential, a shift to IBC technology will be the next logical step; here, not only the n^+ contacts but also the p^+ contacts will be passivated after introducing an industrial cost-effective process for the deposition of B-doped poly-Si. If we could look into a crystal ball, in about 10 years from now IBC technology may well be seen to be gaining a market share of up to 50%.

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About the Authors

Dr. Radovan Kopecek obtained his Diploma in physics at the University of Stuttgart in 1998. He also studied at Portland State University (Oregon, USA), where he obtained a master's in 1995. In 2002 he finalized his Ph.D. dissertation at the University of Konstanz and was a group leader there until the end of 2006. One of the founders of ISC Konstanz, he has been working at the institute as a full-time manager and researcher since 2007 and is currently the head of the Advanced Solar Cells department.

Dr. Joris Libal received his Diploma in physics from the University of Tübingen, and his Ph.D. on the topic of n-type crystalline silicon solar cells from the University of Konstanz. He has been involved in R&D along the entire value chain of crystalline silicon PV in the past, and joined the ISC in 2012. He is currently an R&D project manager, working on technology transfer and cost calculations in the areas of high-efficiency n-type solar cells and innovative module technology, as well as on ISC's activities in energy yield simulations.

Enquiries

Radovan Kopecek
ISC Konstanz
Rudolf-Diesel Straße 15
78467 Konstanz, Germany

Email: radovan.kopecek@isc-konstanz.de
Website: www.isc-konstanz.de