International Solar Energy
Research Center Konstanz

BIFACIAL PHOTOVOLTAICS

TECHNOLOGY, APPLICATIONS AND ECONOMICS

Dr. Radovan Kopecek, J. Libal et al.

PV in 2020

LARGE SCALE SOLAR DIGITAL SERIES

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Total installed PV systems of ca. **650GW**

Expected installation in 2020 are **140GW**

End 2019: Total installed renewables capacity hit a remarkable 2,564 GW, with hydropower remaining the dominant source at 1,311 GW, followed by **wind at 623 GW** and **PV at 585 GW**. .

1TW PV to come **in 2022**; 30-70TW expected in 2050

Module prices below **20USct/Wp**

LCOEs below **2USct/kWh** possible (lowest 1.35USct/kWh)

LCOEs at **1USct/kWh to come soon with bifacial HSAT**

PV in 2020: lowest bids

First bid below $0.02/kWh was bifacial HSAT from EDF/Masdar ($0.0179/kWh) in 2017 in Saudi Arabia

>> rejected also because bifacial PV was not bankable at that time

TaiyangNews
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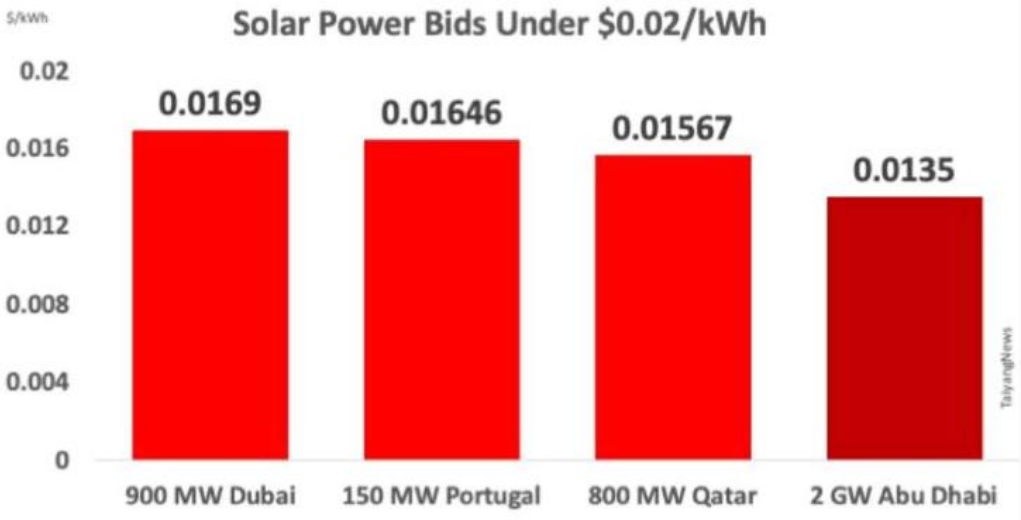
+ Folgen

Abu Dhabi Power Corporation Reveals $0.0135/kWh As Lowest Winning Tariff For 2 GW Al Dhafra **#Solar** **#PV** Project, Lowest So Far For Solar… mehr anzeigen

Übersetzung anzeigen



World's Lowest Solar Tariff For 2 GW Abu Dhabi

PV in 2020: bifacial forecast

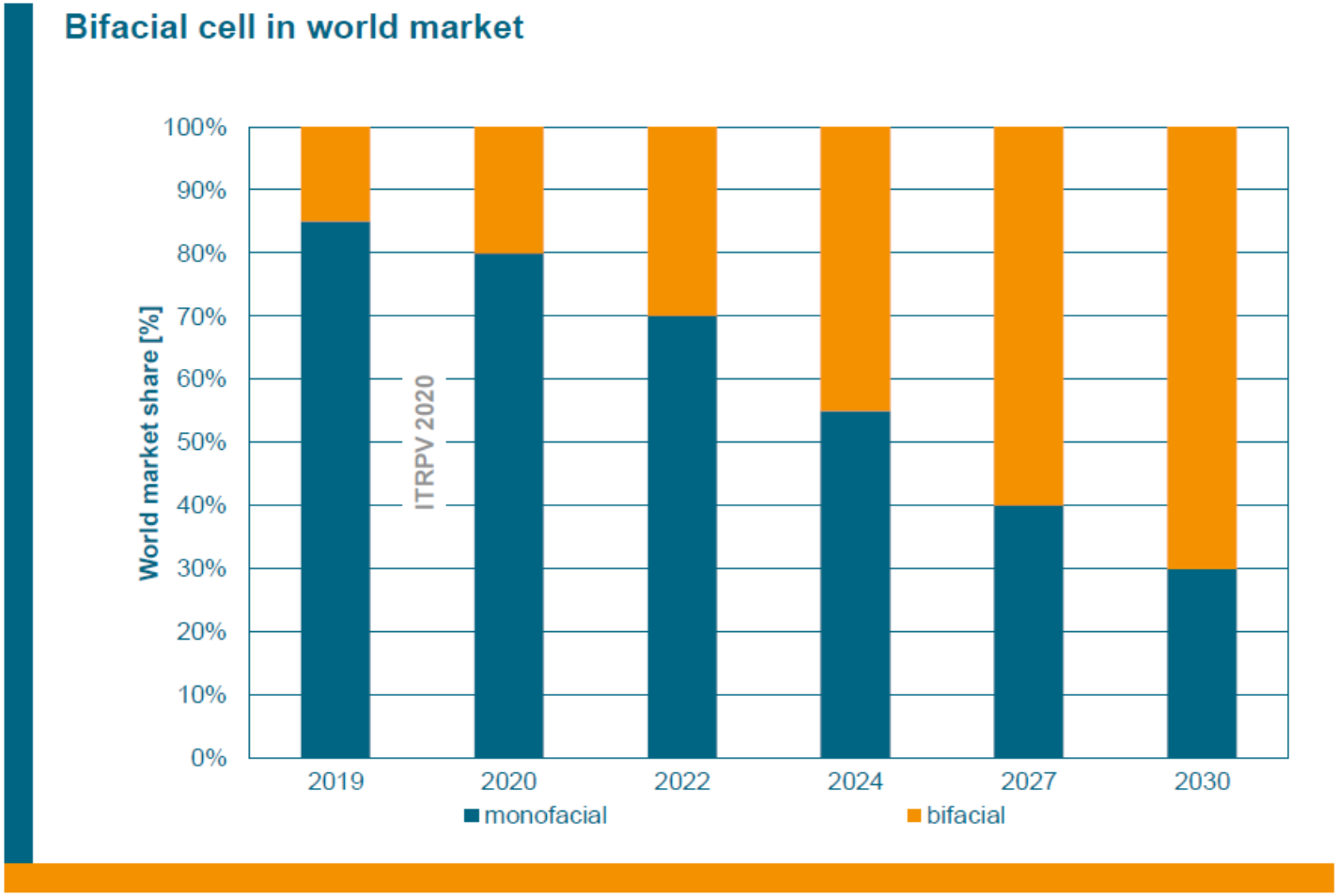


Fig. 40: Worldwide market shares for bifacial cell technology.

PV in 2020: bifacial forecast

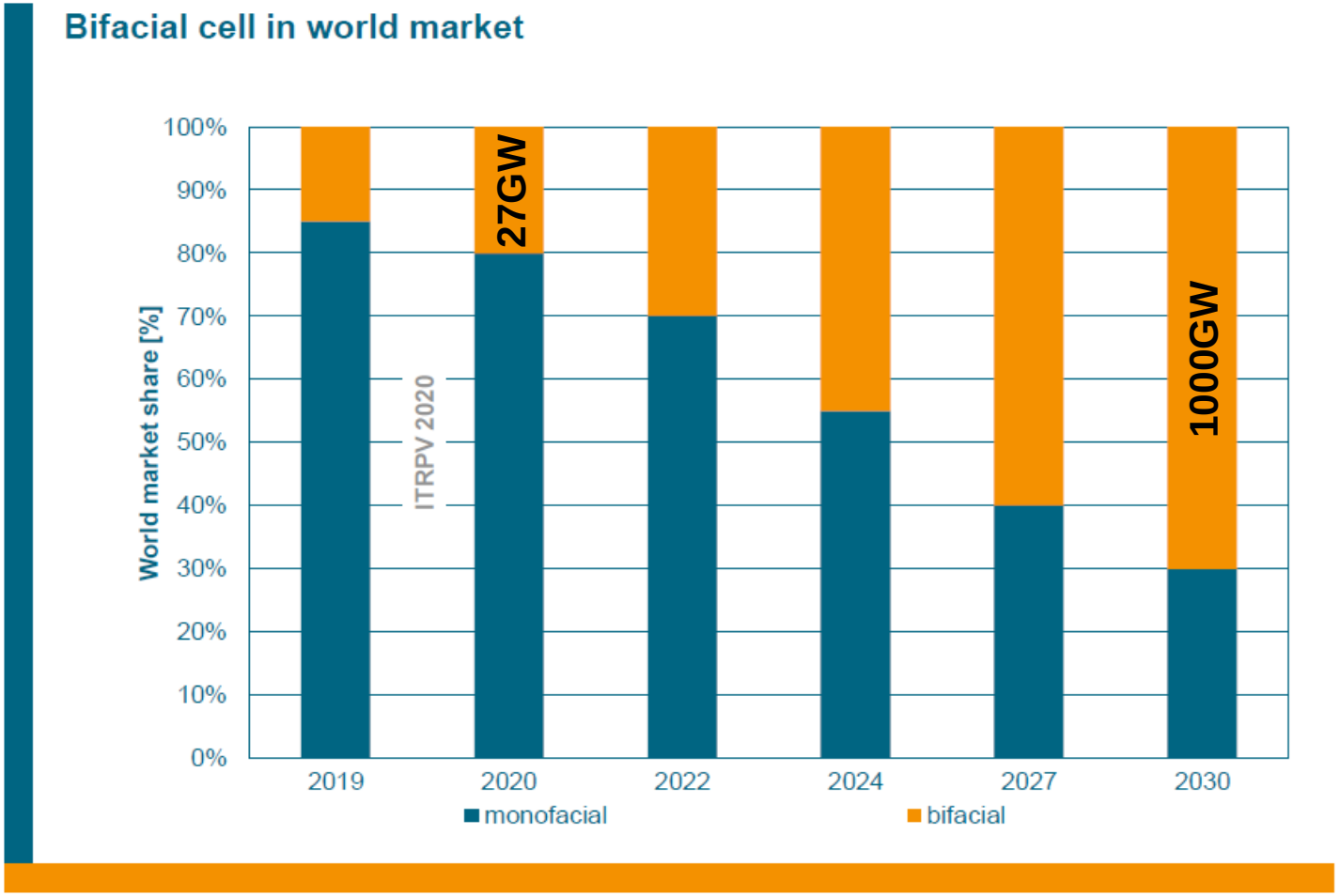


Fig. 40: Worldwide market shares for bifacial cell technology.

agenda

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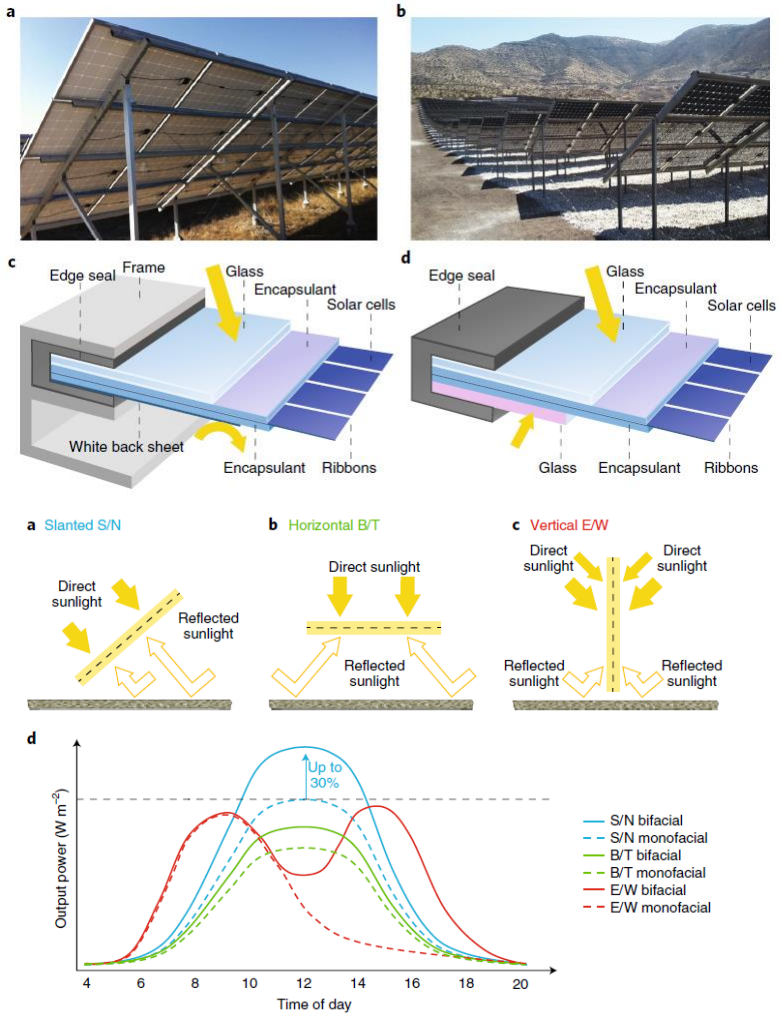
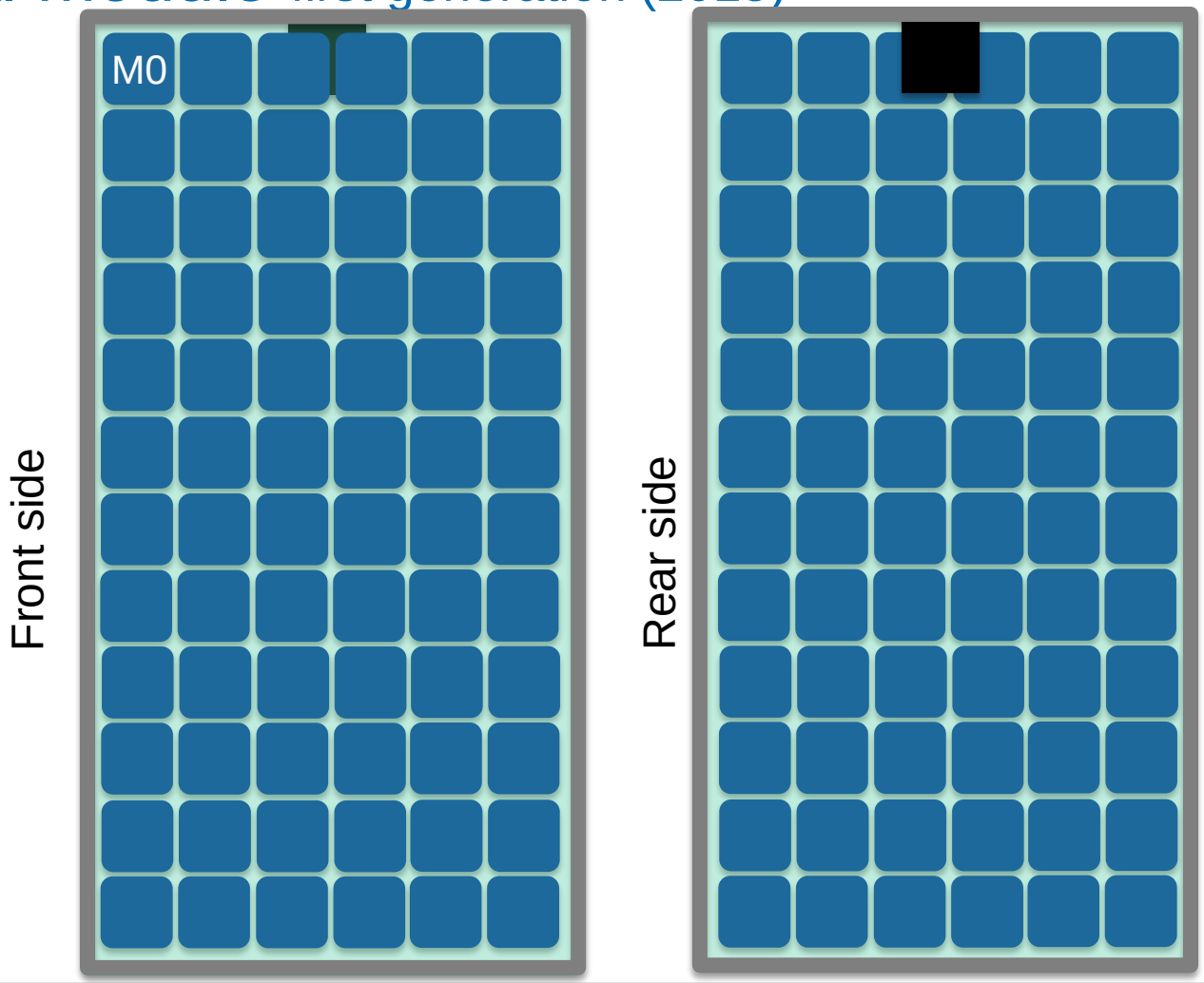
- What is a bifacial module?
  structure / history / properties / standards
- Where are bifacial modules being used?
  differed PV systems / utility scale / commercial / roof top
- What are the most notable benefits and risk factors?
  enhancement of the energy yield / additional degradation mechanisms
- In introduction to albedo and how it affects bifacial performance
  definition of albedo / albedo of different systems



Kopecek and Libal, Nature Energy 3,443–446 (2018)

Bifacial module technologies

Bifacial module first generation (2015)



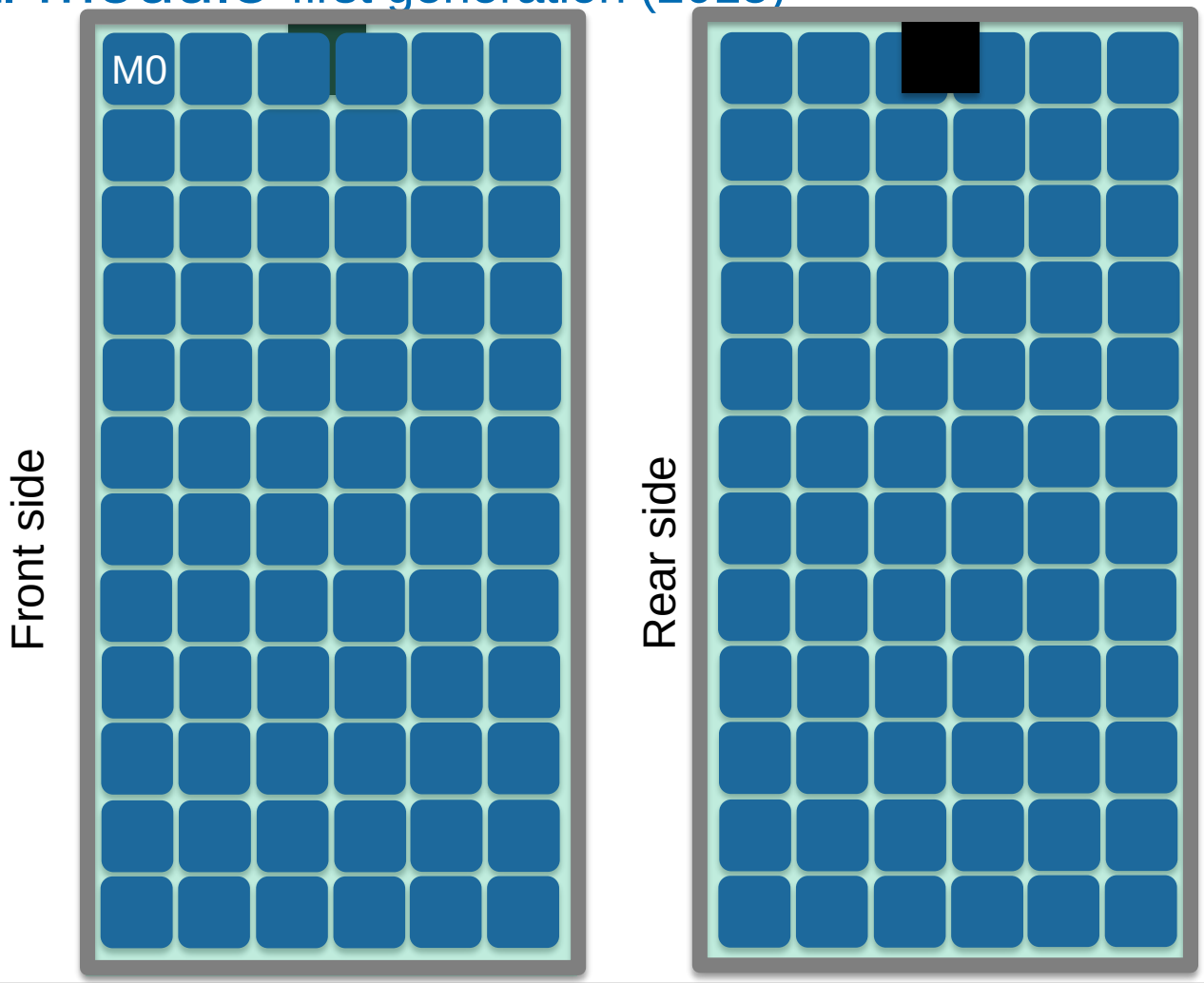
Bifacial module technologies

Bifacial system first generation (“La Hormiga” in Chile)


BiSON

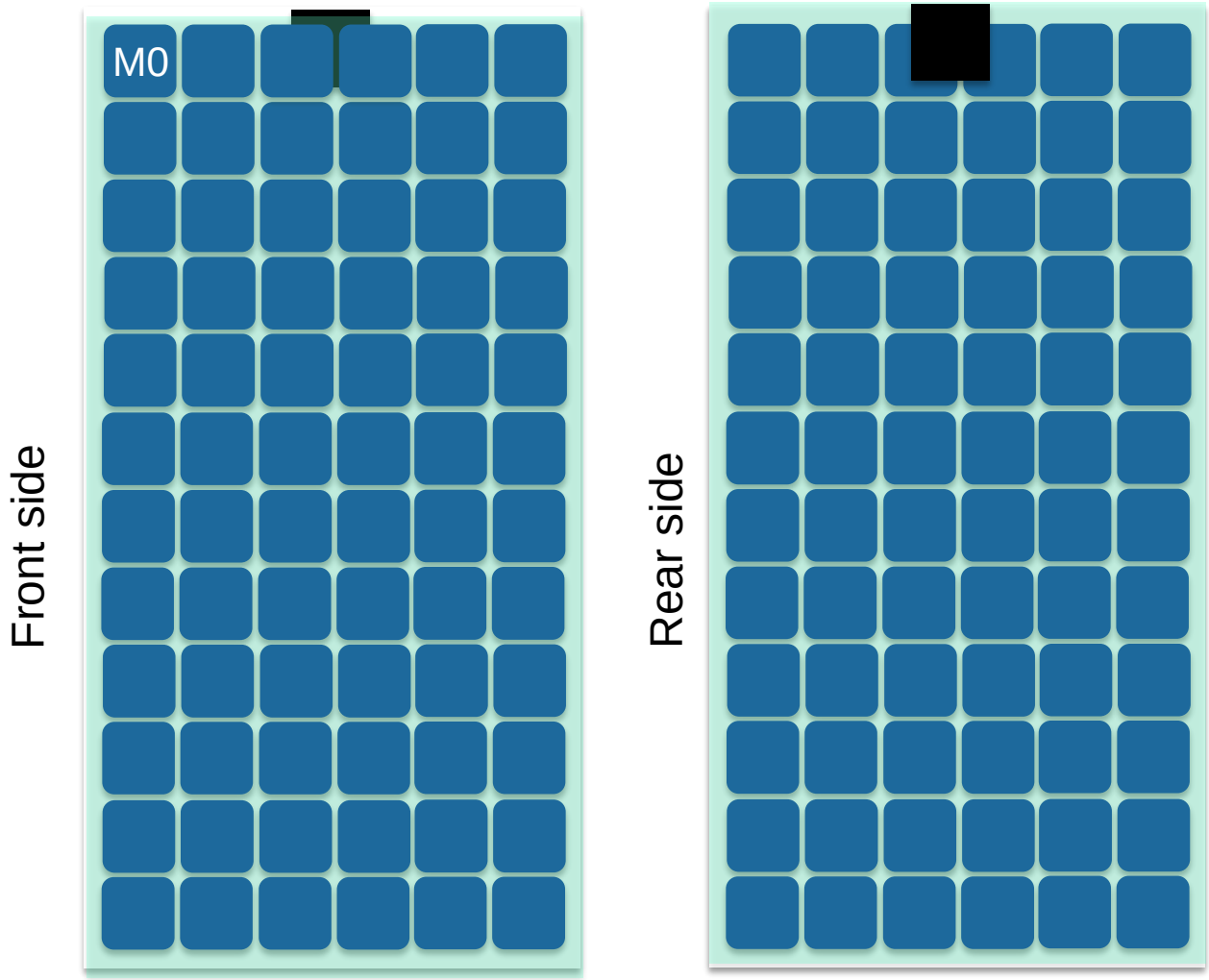
Bifacial module technologies

Bifacial module first generation (2015)



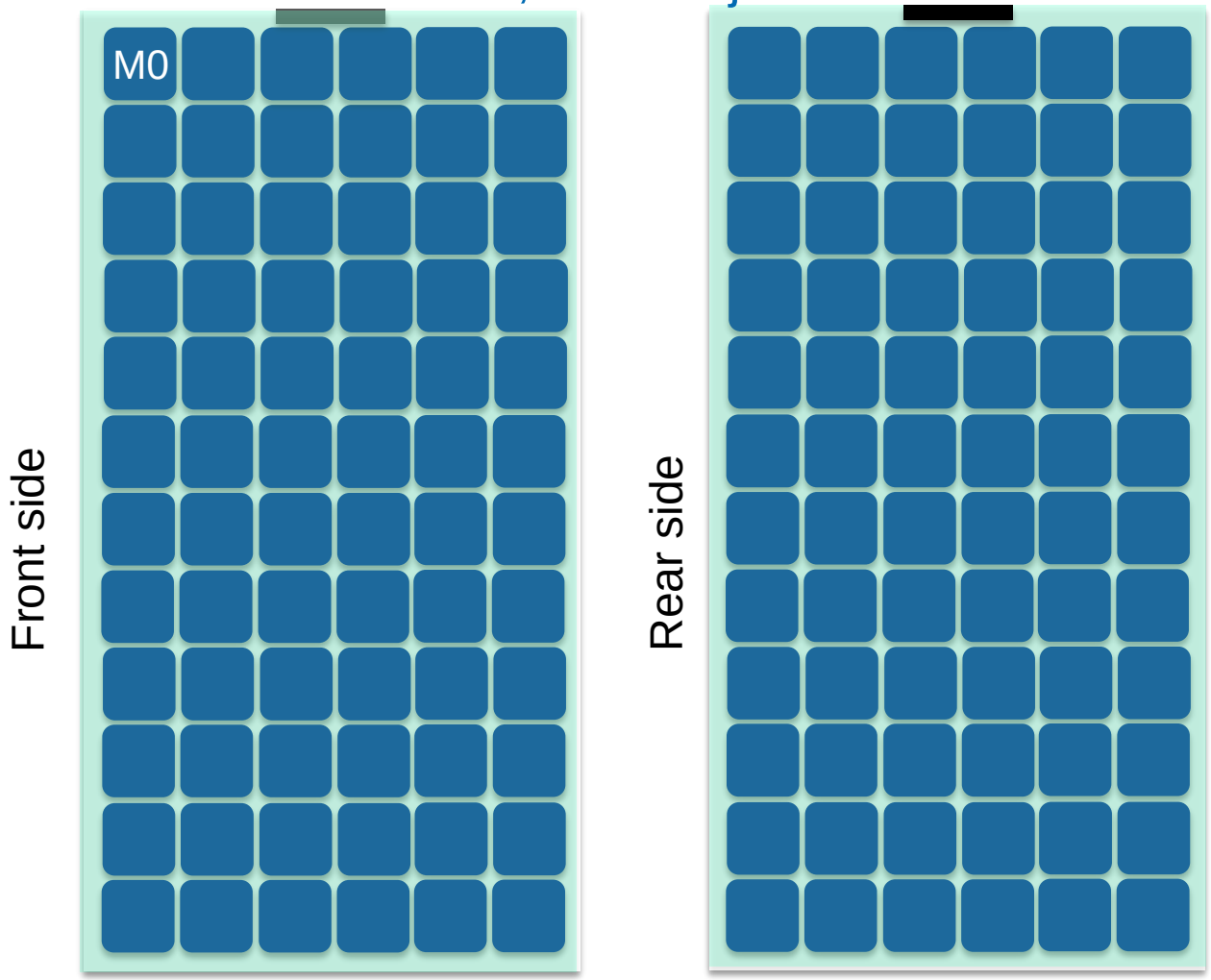
Bifacial module technologies

Bifacial module frameless



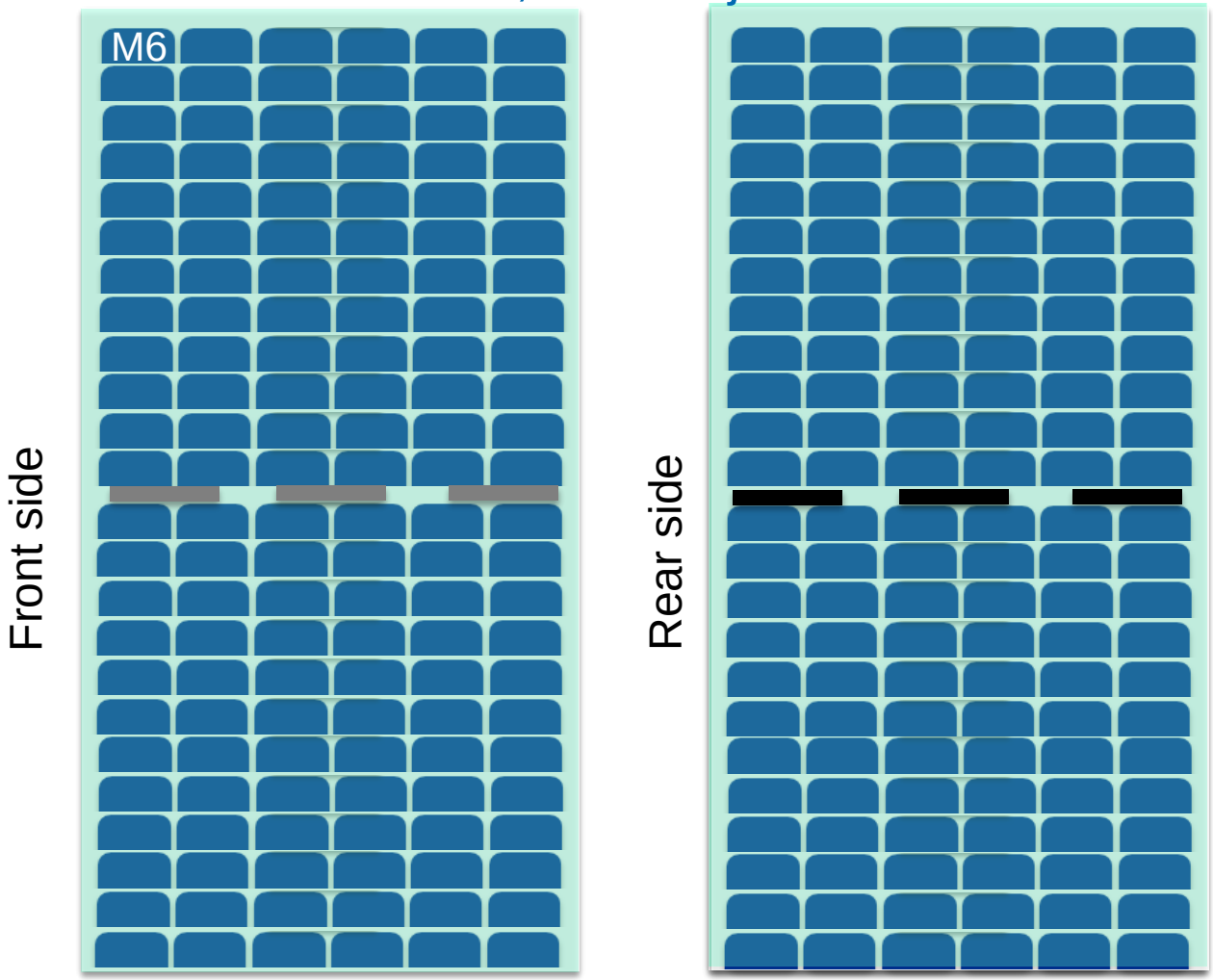
Bifacial module technologies

Bifacial module frameless, shallow junction box



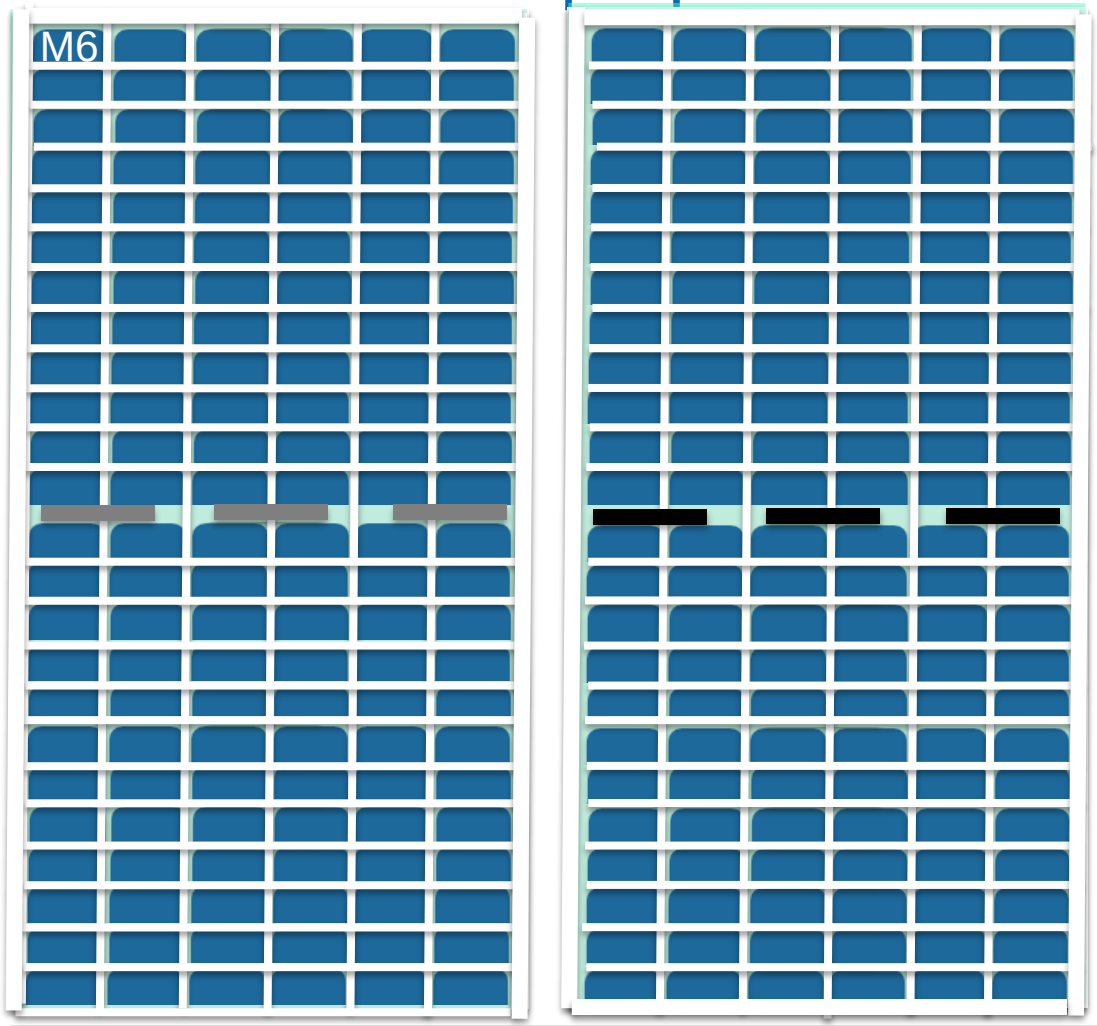
Bifacial module technologies

Bifacial module frameless, shallow junction box and half cells



Bifacial module technologies

Bifacial module: properties



- **frameless**
(or with frame)

- **double glass**
(or transparent backsheet)

- **shallow junction box**
(or split junction boxes)

- **Polyolefin**
(or EVA or no enc. (NICE))

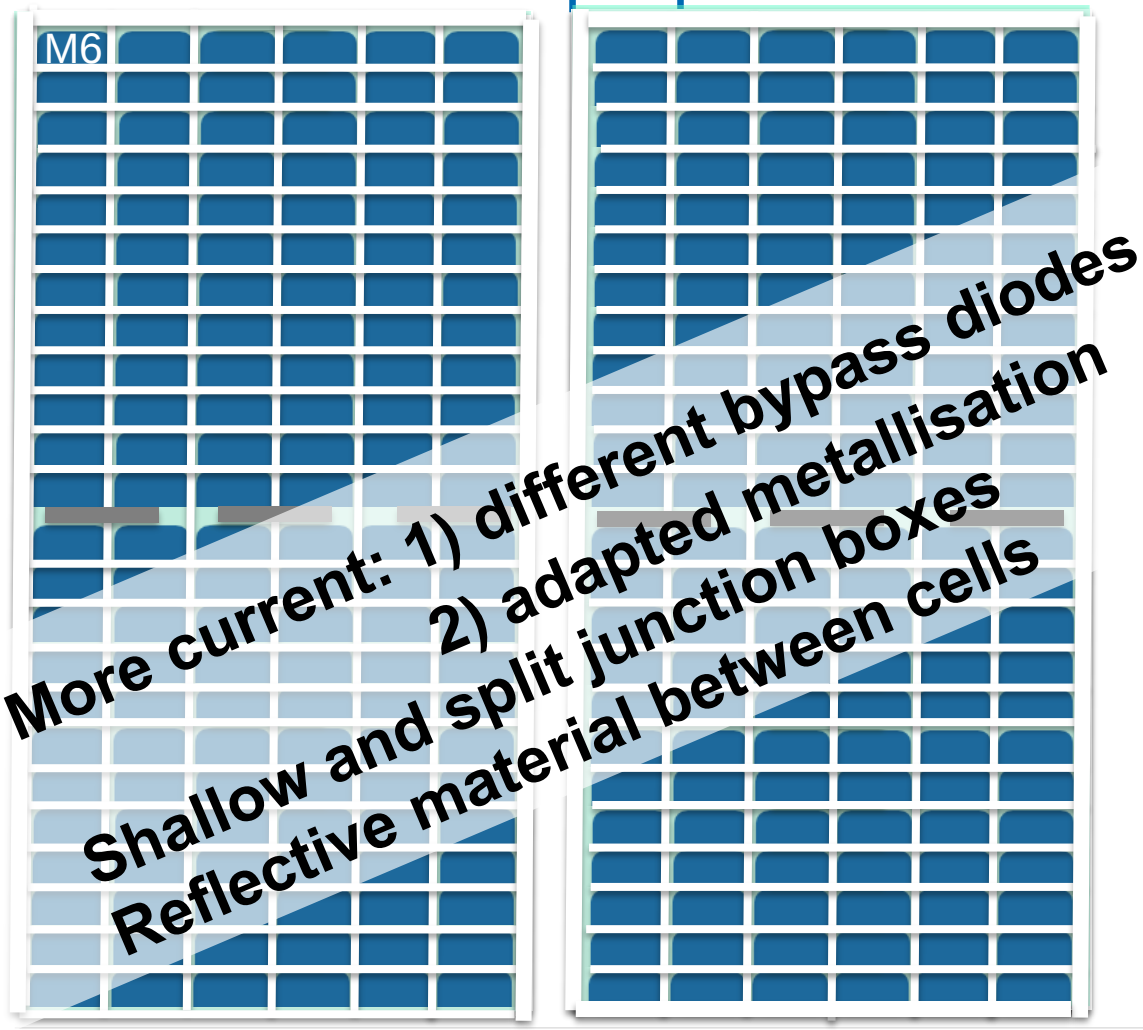
- **n-type solar cells**
(or p-type)

- **5-6 BB solar cells**
(or multi BB, or shingling)

- **half cells**
(or full cells)

Bifacial module technologies

Bifacial module: properties



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Bifacial module technologies

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Bifacial modules: M6 and M12

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M6: bifacial double-glass from
LONGI Hi-MO3 450W+

M12: bifacial double-glass from
TRINA Duomax V **500W+**

JinkoSolar Launches 2020 Flagship **Tiger Pro Series** with Module Output of **Up to 580W**

Bifacial module: IBC (ZEBRA)

International Solar Energy Research Center Konstanz

Bifacial Solar Module Technology 2018 Edition

Bifacial back contact: Every advanced cells technology is betting on a share in the promising bifacial segment, research center ISC has tweaked its IBC cell, which it offered under the name ZEBRA. Pictured is ISC managing director Radovan Kopecek with a module from Spic Xi'An Solar Power Co., Ltd.

TAIYANGNEWS ALL ABOUT SOLAR POWER

ISC´s M6 ZEBRA (450W+) is also bifacial with BF of 0.7+

(not yet on the market)

Bifacial module: IBC (ZEBRA)

International Solar Energy Research Center Konstanz

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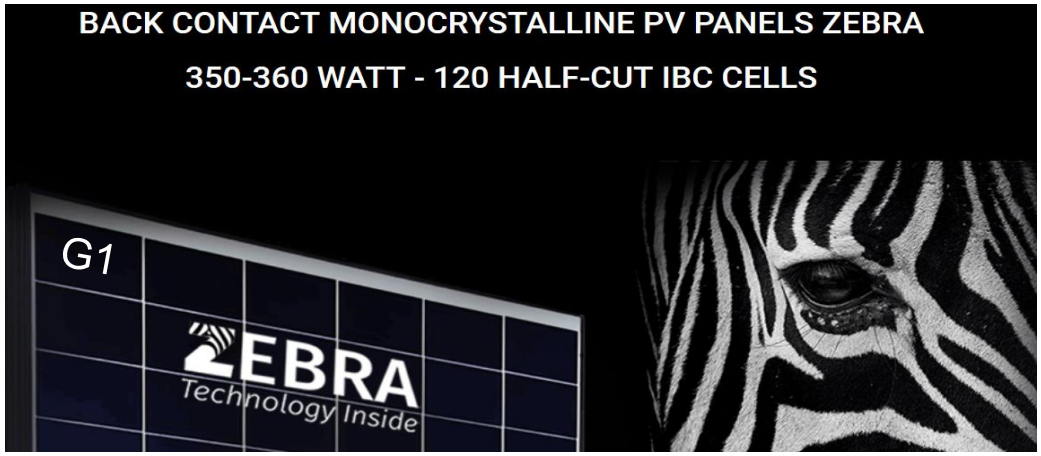

TAIYANGNEWS ALL ABOUT SOLAR POWER

Bifacial module: history of bifacial cells

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History of bifacial cells/modules

1. First cell in 1954 from Bell Labs: bifacial n-type IBC
2. Change to p-type because of space PV
3. Terrestrial Al-BSF >> MONOFACIAL
4. In 2000 n-type low cost bifacial
5. Bifacial PV was growing slowly: 2013 first 1.25MW system in Japan
6. PERC from 2016
7. >> BIFACIAL PV BECOMIG BIG!!
8. >> Total installation end 2019 of 5GW

Module power

1. What will come next after PERC??
2. In order to increase module power wafer sizes are increased

M0 >> M2 >> G1 >> M4 >> M6 >> M12

Bifacial module: bifacial cells

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Table 2.1 Bifacial solar cells and their main parameters

	Cell concept	Bifaciality factor (on cell level)	Si base material	Junction and BSF doping method	Contacts	(Front) Efficiency potential
2.5.1	Heterojunction	>92%	n mono	a-Si:H p- and n-type doped	TCO/Ag printed TCO/Cu plated	22%–25%
2.5.2	n-PERT	>90%	n mono	Boron and Phosphorous diffusion	Ag and Ag/Al printed	21%–22%
2.5.3	p-PERT	>90%	p mono	Phosphorous and Boron diffusion	Ag and Ag/Al printed	21%–22%
2.5.4	PERC+	>80%	p-mono	Phosphorous diffusion and local Al BSF	Ag and Al printed	21%–22%
2.5.5	IBC	>70%	n-mono	Boron and Phosphorous diffusion	Ag and Ag/Al printed	22%–23%

J. Libal and R. Kopecek Bifacial book 2018

Bifacial module: bifacial cells

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Bifacial panel: BF and measurement

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$P_f(1sun) = 450W$ example

1sun >> P_f

Bifacial panel: BF and measurement

$P_f(1sun) = 450W$

$Pr(1sun) = 315W$

$BF = 0.7$

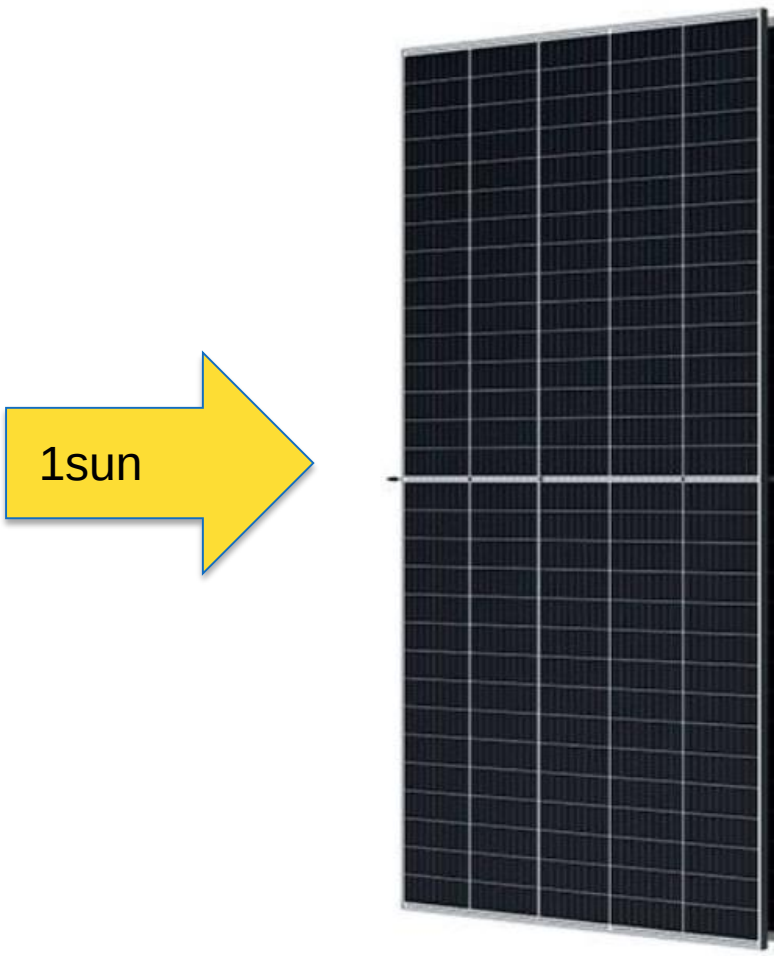
example

1sun >> P_r

formula

$$BF = P_r(1sun)/P_f(1sun)$$

Bifacial panel: BF and measurement



$P_f(1sun) = 450W$ example

$Pr(1sun) = 315W$

$BF = 0.7$

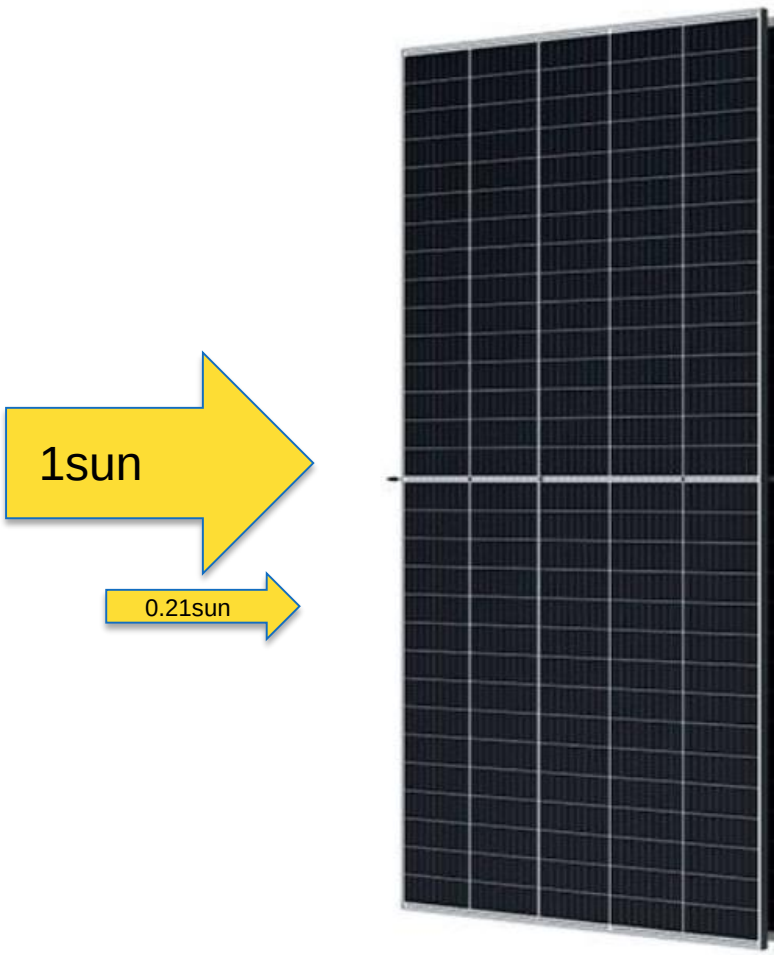
$P_{bifi300}$ (2 sides illum.) $= 545W$

formula

$$BF = P_r(1sun)/P_f(1sun)$$

$$P_{bifi300} = P_f(1sun)+P_r(0.3sun)$$

Bifacial panel: BF and measurement



$P_f(1sun) = 450W$ example

$Pr(1sun) = 315W$

$BF = 0.7$

$P_{bifi300\ (2\ sides\ illum.)} = 545W$

$P_{bifi300\ (1\ side\ illum.)} = 545W$

formula

$$BF = P_r(1sun)/P_f(1sun)$$

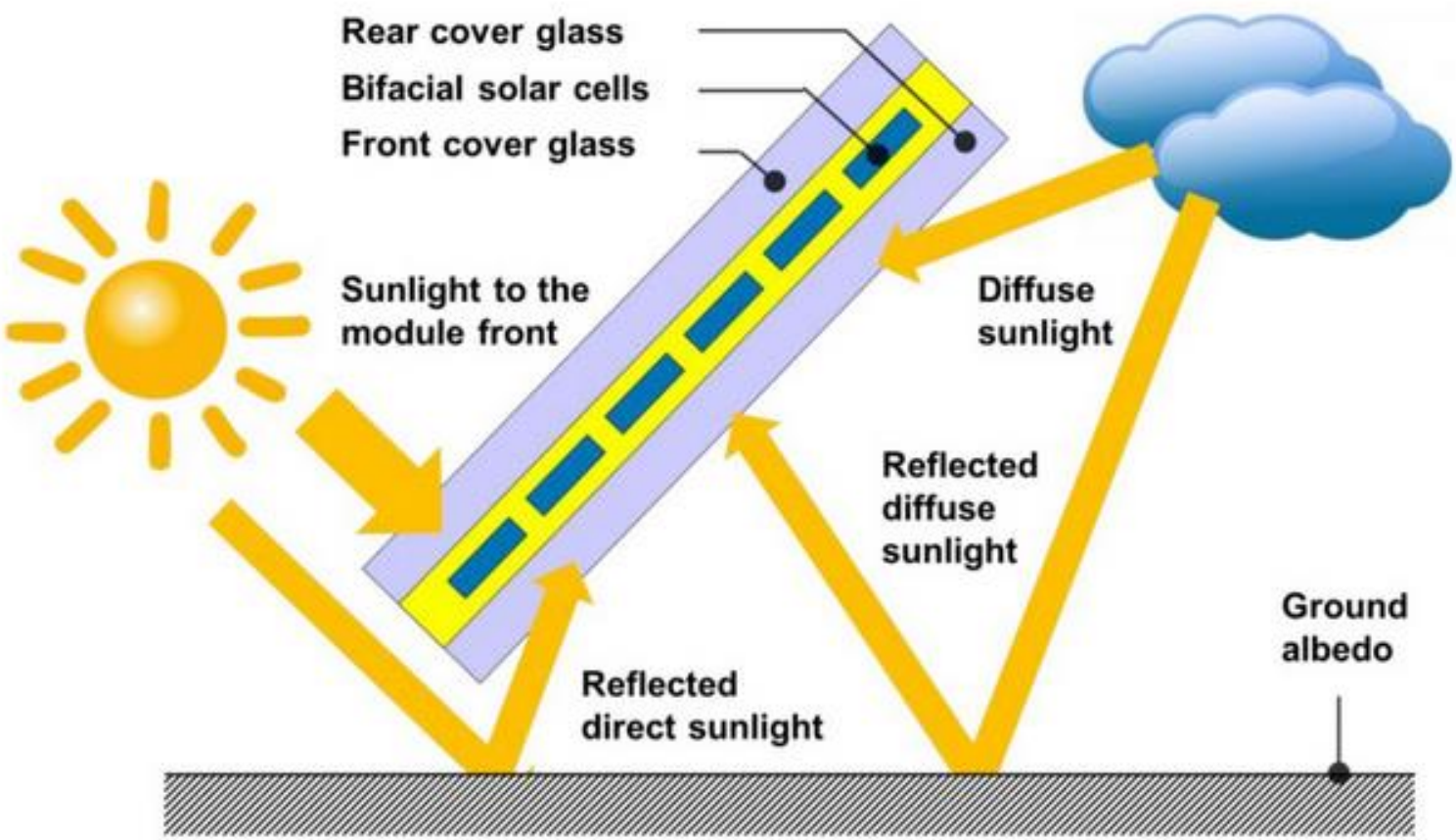
$$P(bifi300) = P_f(1sun)+P_r(0.3sun)$$

$$P(bifi300) = P_f(1sun)+P_f(0.3sun*BF)$$

Technical specification (TS)
IEC 60904-1-2: active from January 2019

Bifacial applications and market

Bifacial PV: reflections



picture: TÜV Rheinland

Nature Energy June 2018: bifaciality

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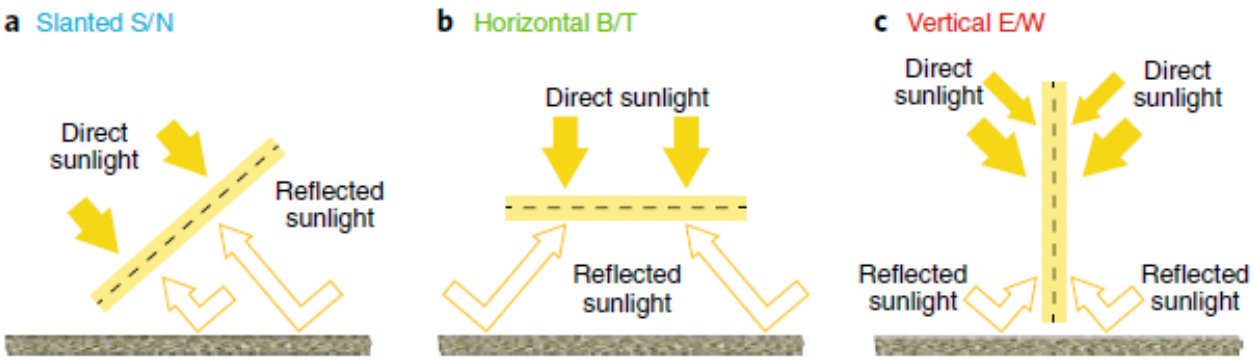
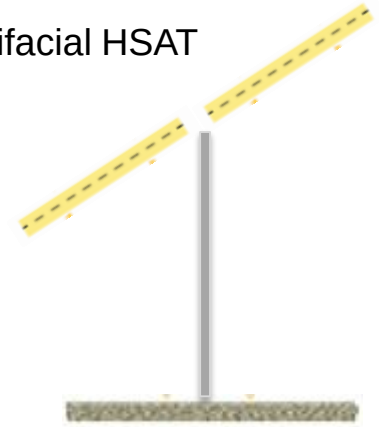
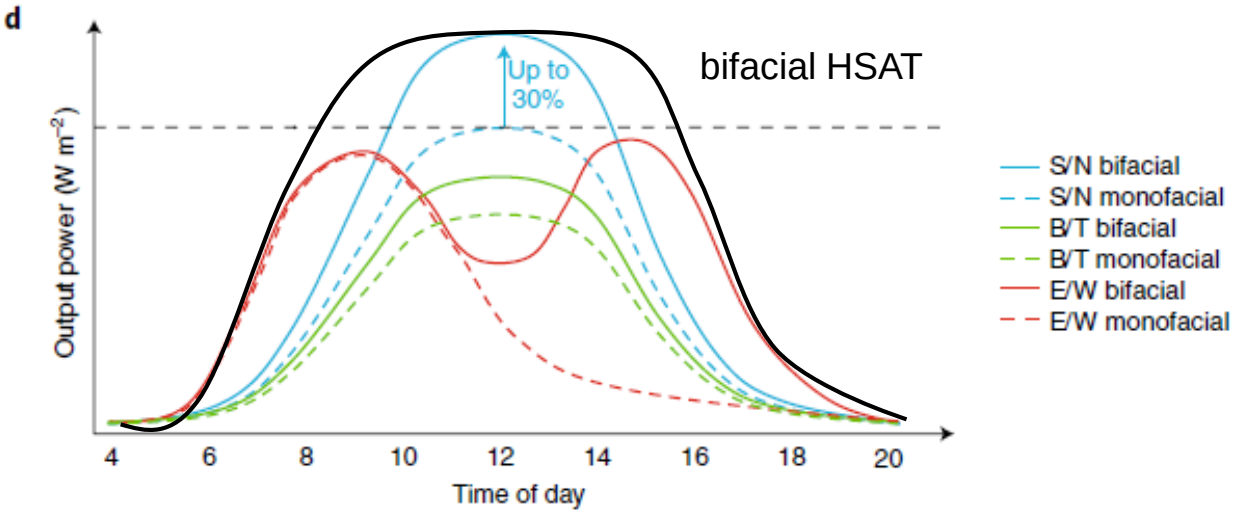


bifacial HSAT





Bifacial fixed tilt: 7-30% BG
Bifacia HSAT: 5- 25% BG

Kopecek and Libal, Nature Energy 3,443–446 (2018)

Bifacial gain

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ALBEDO

module´s bifaciality

installation geometry

height & row distance (GCR)

latitude

Bifacial PV market

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utility scale

fix tilt

vertical

tracking

industrial and residential flat roof

fix tilt

vertical

tracking?

working on it

building integration carports/ sound barrier

fix tilt

vertical

vertical

Bifacial PV market

LARGE SCALE SOLAR DIGITAL SERIES

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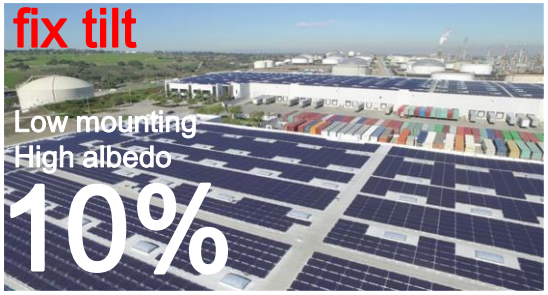

vertical

tracking?

working on it

building integration carports/ sound barrier

fix tilt

vertical

vertical

Status of bifacial installations 2020

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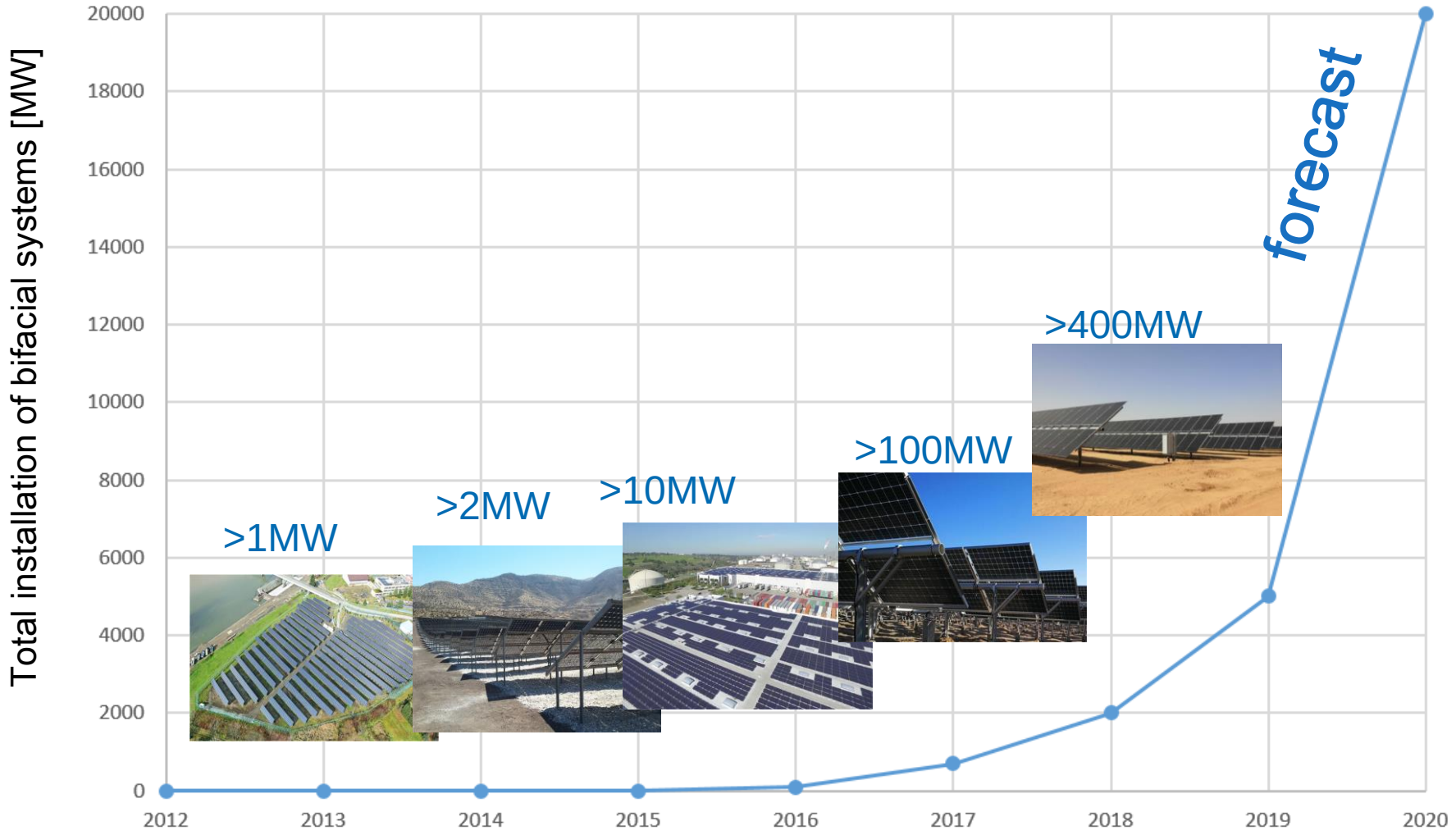

R. Kopecek, LARGE SCALE SOLAR digital series, 18. 05. 2020

Status of bifacial installations 2020

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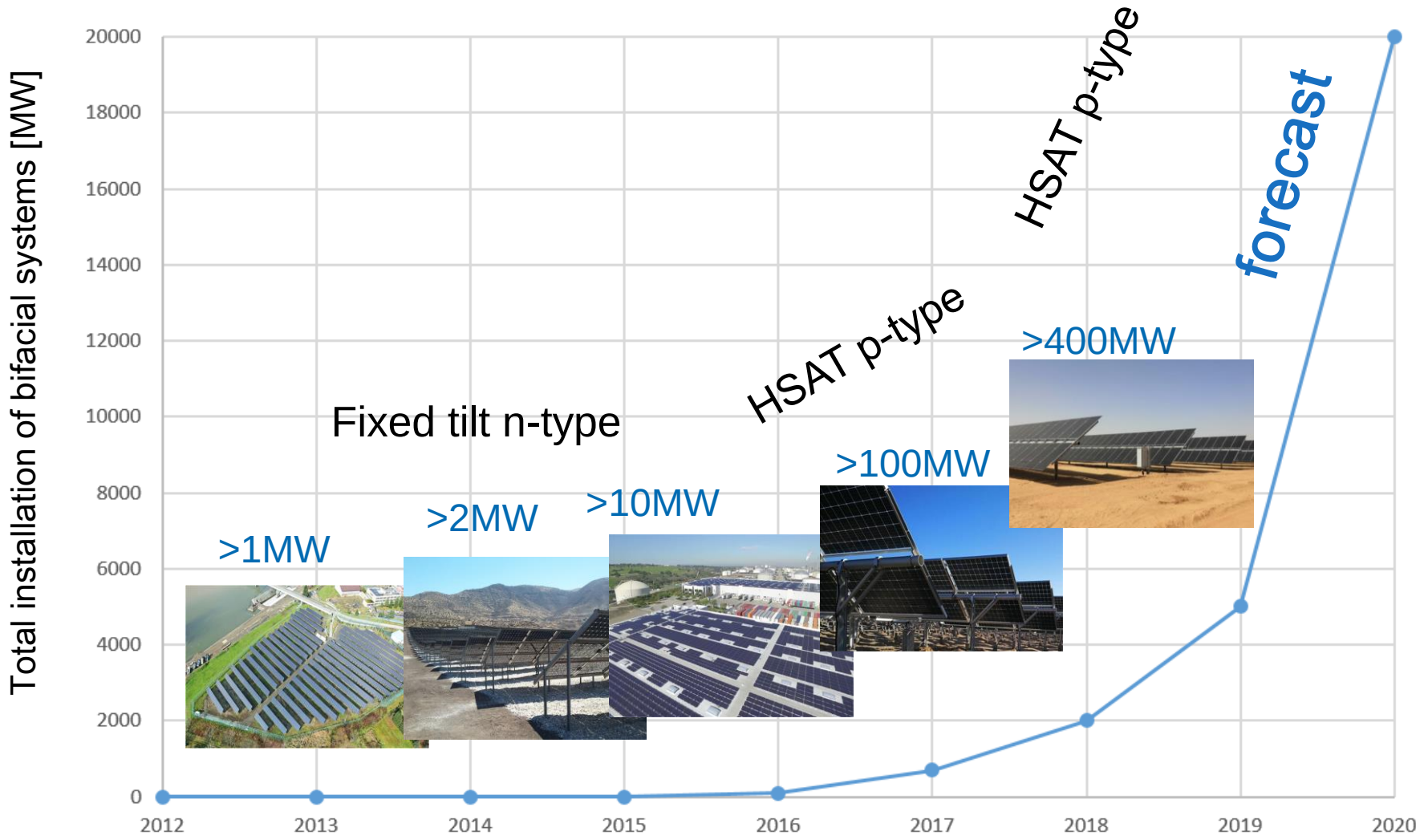

2018: 2GW+ bifacial installations

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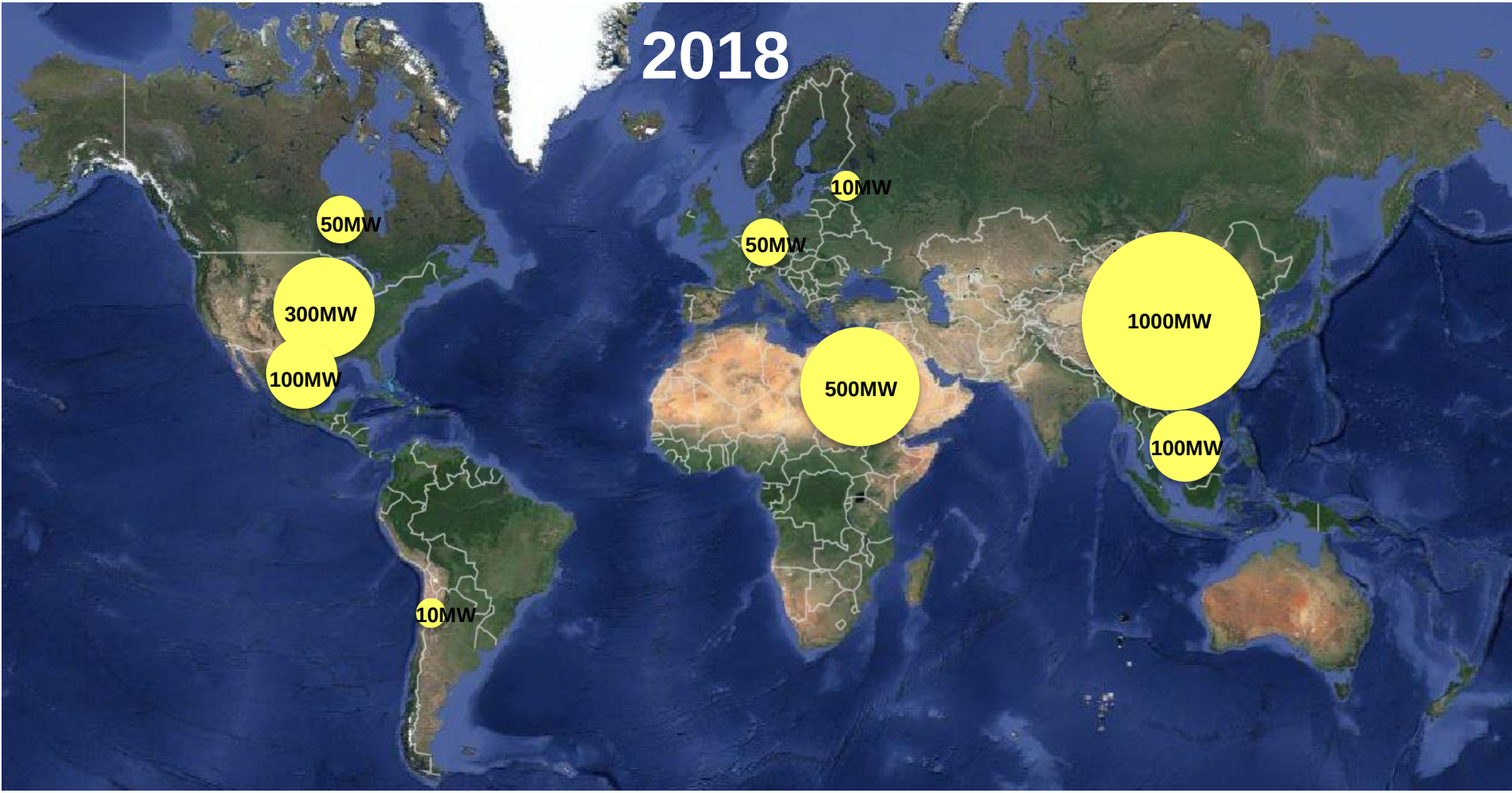

2020: 20GW forecast

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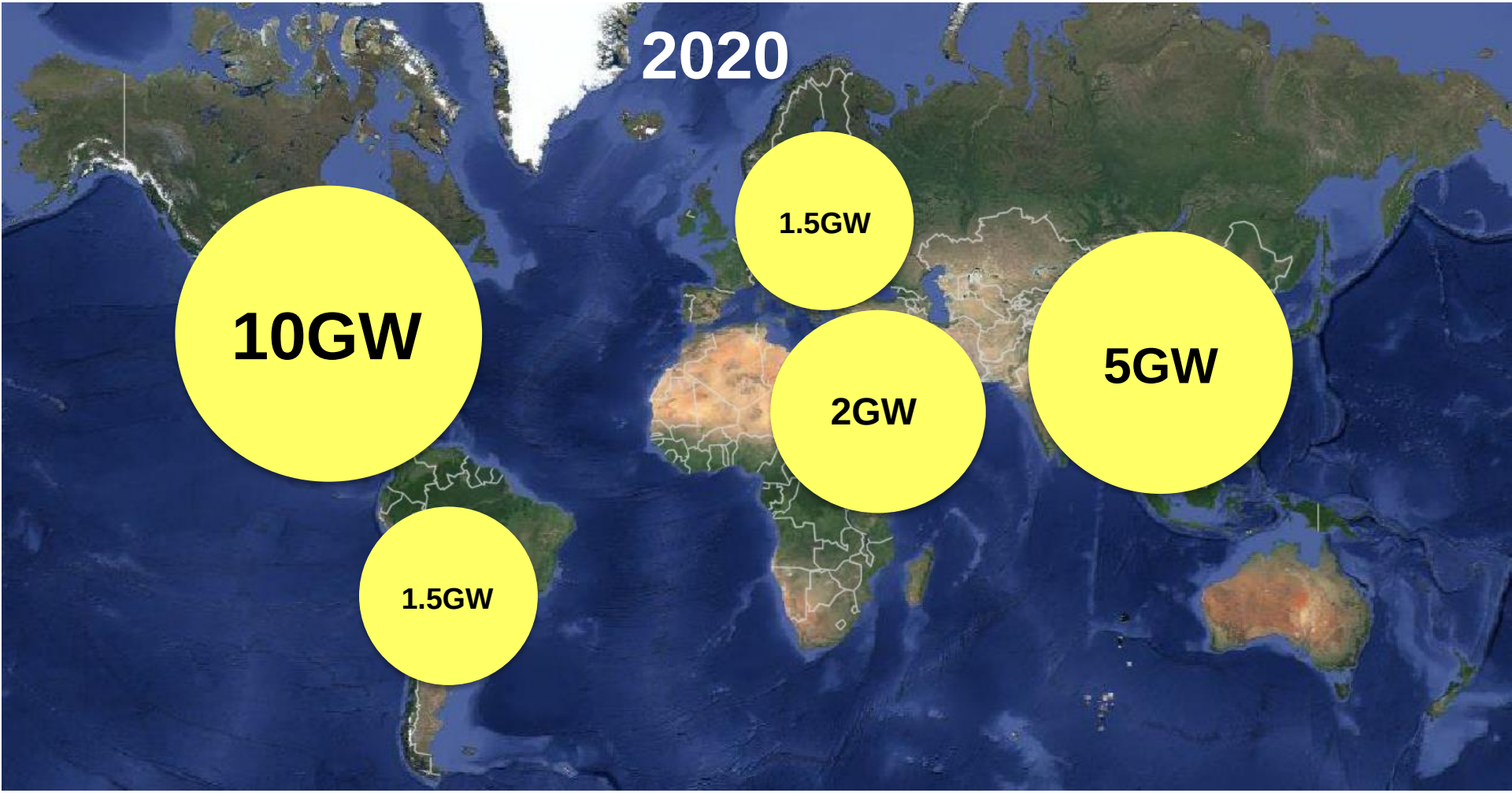

Electricity costs from PV (utility scale)

for 1500 kWh/kWp

Electricity costs from PV (utility scale)

International Solar Energy Research Center Konstanz

for 1500 kWh/kWp

Bifacial PV: benefits and risks

Bifacial PV: benefits and risks

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Benefits

- Generation curve shaping
- Low GCR (vertical even 0)
- Nice appearance
- Snow melting
- Agro PV

Higher yearly yield

Risks

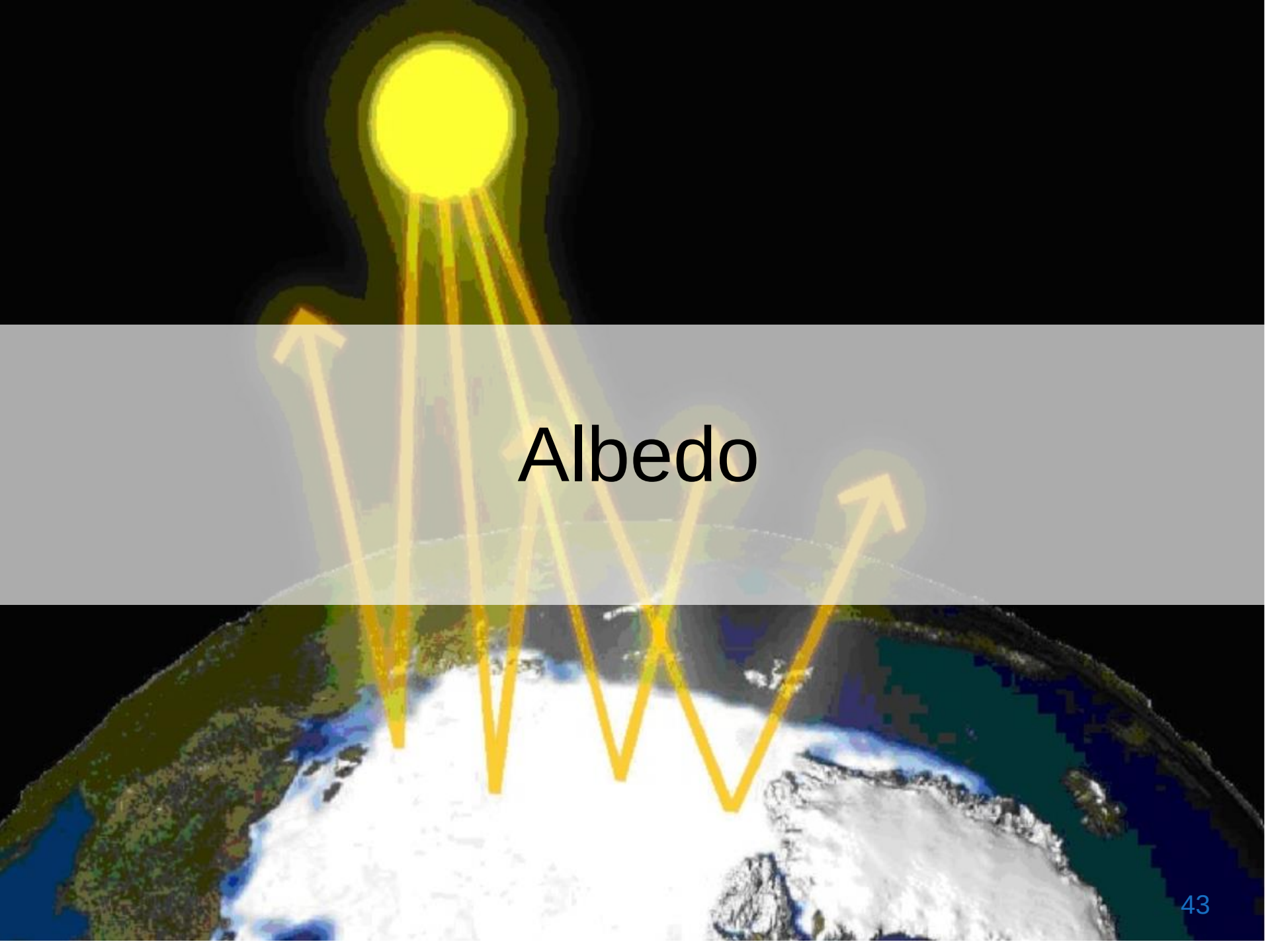
Overestimation of yearly yield?

There are several simulation programs which can precisely simulate the yearly yield: PVsyst, MoBiDiG, Great Eye, SAM,
> better simulations needed

Better maintenance of system?

Higher degradation of bifacial modules?

LeTID, PID, rear side finger degradation, transparent back sheet degradation etc. can have a higher impact on module aging
> better testing needed



Albedo

Albedo: definition and measurement

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The albedo of a surface describes its capacity of reflecting short-wave radiation (300 to 3000 nm) from the sun.

The albedo is defined as the ratio of the reflected radiation to the incoming radiation and varies from 0 (0% = black) to 1 (100% bright white).

An Albedometer consists of two pyranometers. The upwards looking pyranometer measures incoming global solar radiation, while the downwards looking pyranometer measures the solar radiation reflected from the surface below

Albedo: different surfaces

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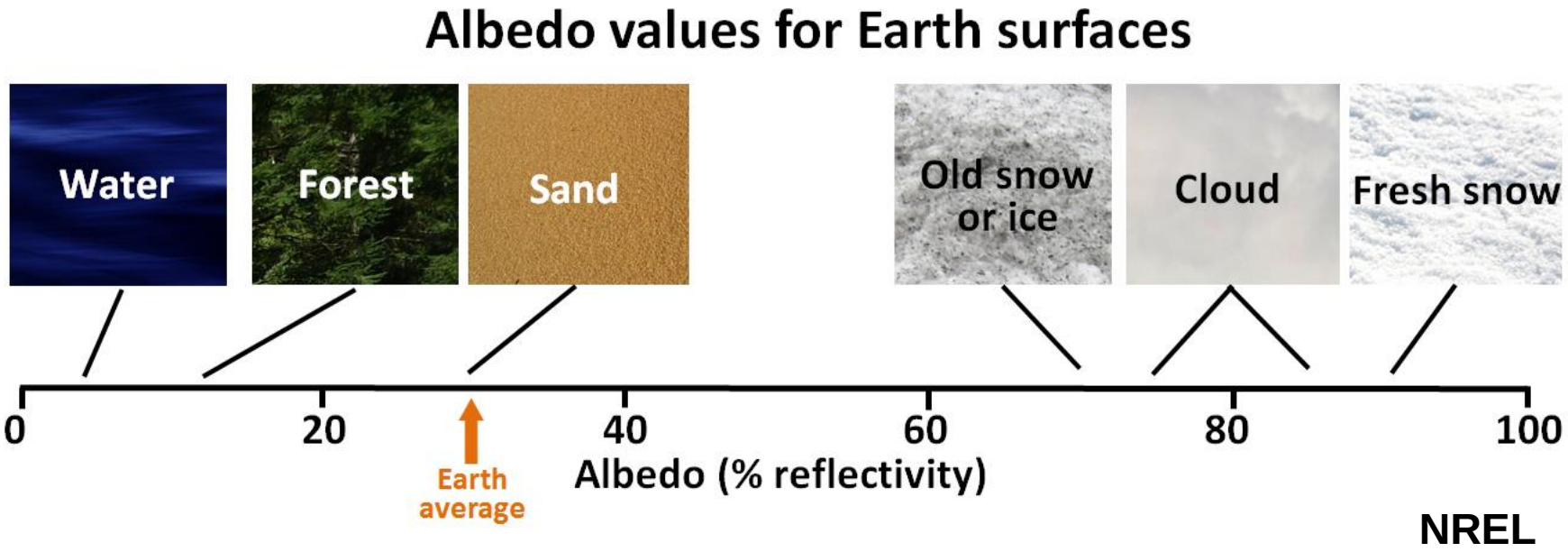

Bifacial gain in dependence of albedo

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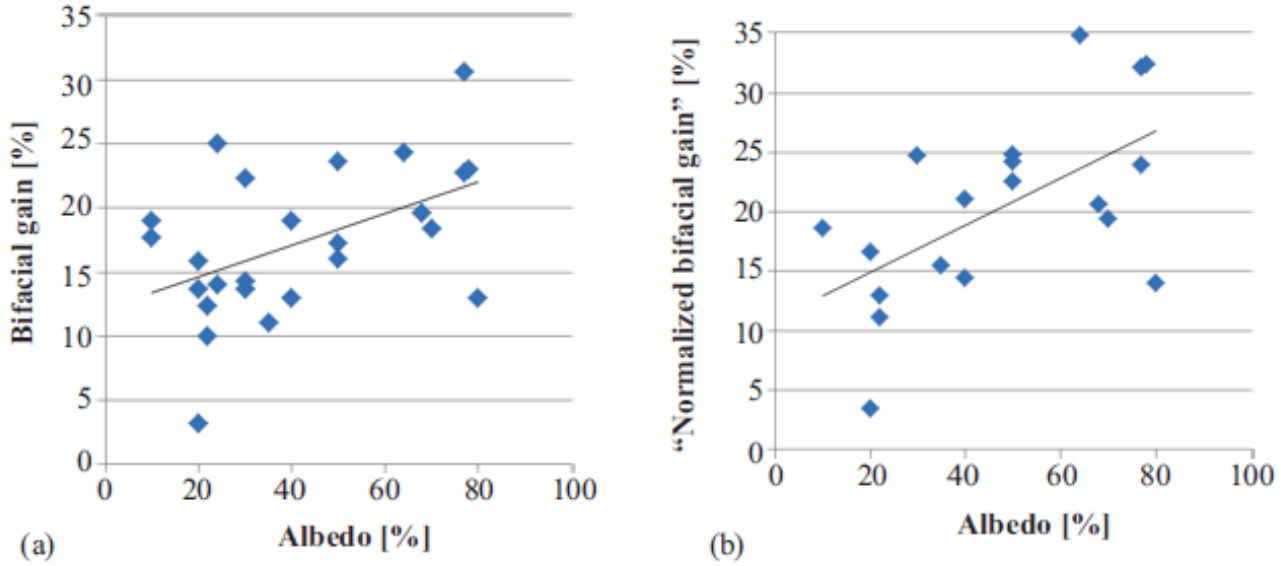

Figure 5.19 *(a) Bifacial gain plotted versus the albedo for "typical" south-oriented arrays. The trend is visible, but the fluctuation range is significant. The smallest observed bifacial gain is above of 10%, except of one outliner. (b) "Normalized bifacial gain" as an attempt to take the different bifaciality factors into account. No obvious improvement and reduced amount of data, but the concept may be useful when comparing more similar PV installations*

J. Libal and R. Kopecek, *Bifacial Photovoltaics: Technology, Applications and Economics*, IET 2018

Bifacial gain in dependence of albedo

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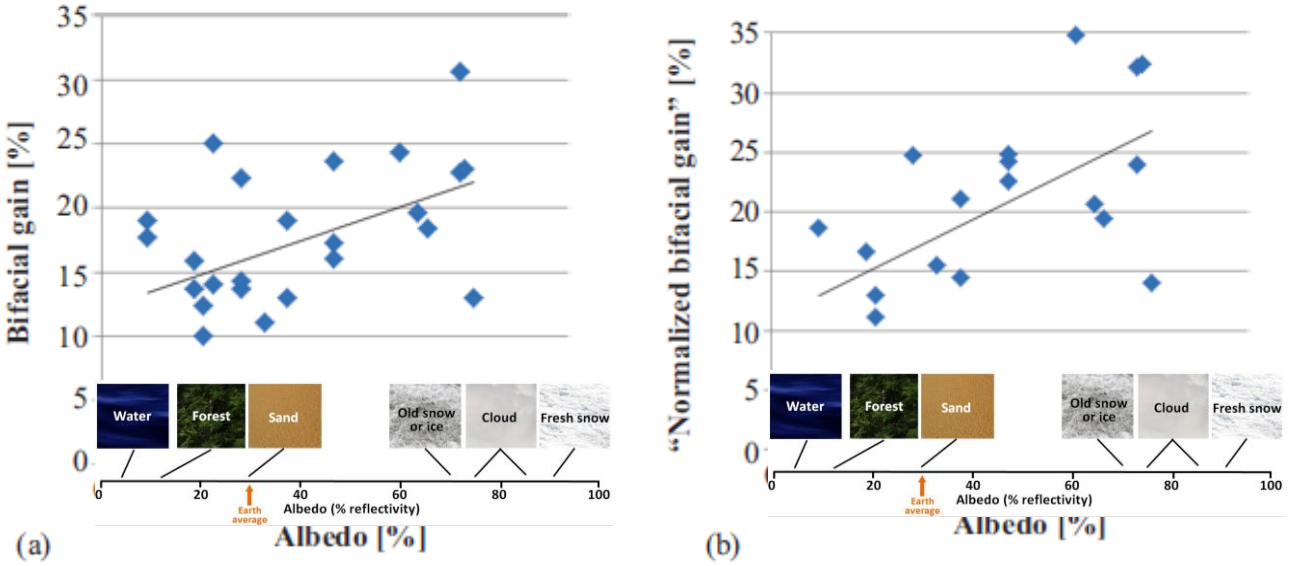

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Summary, conclusion and outlook

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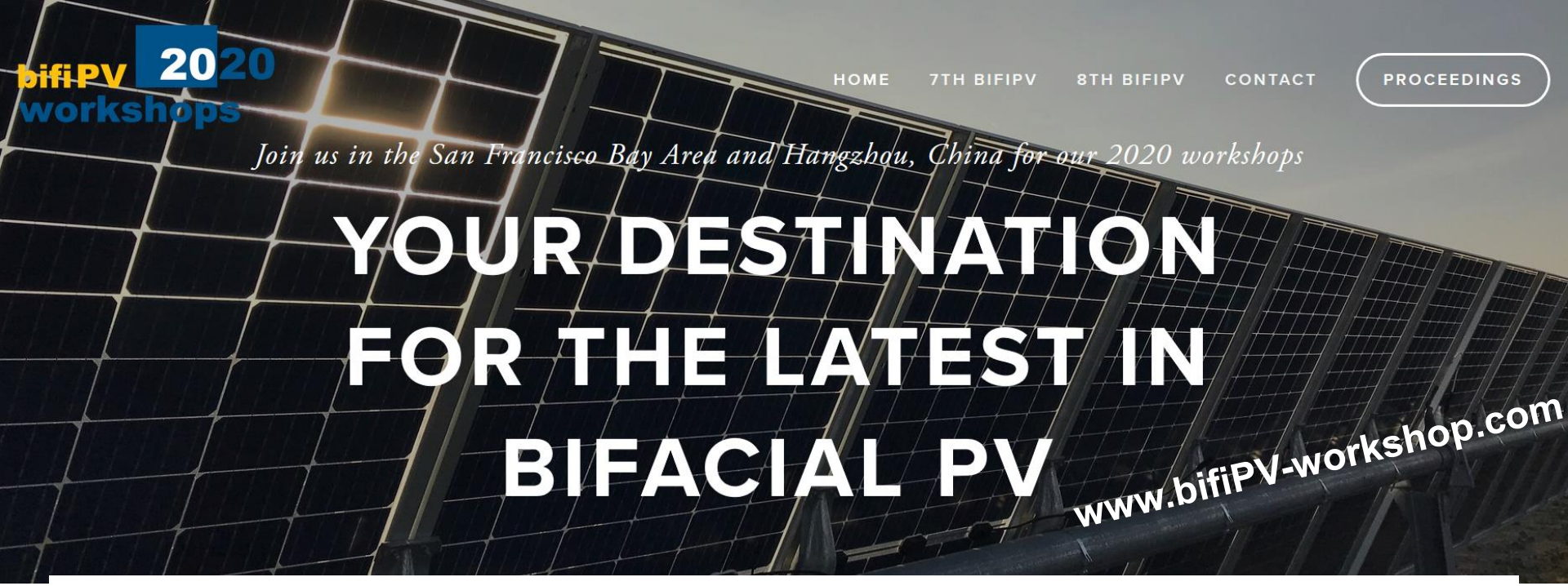
- Bifacial technology offers an increase of energy yield at low additional costs

- Bifacial PERC technology is at the moment dominating the market

- Better module testing and energy yield simulations required

- With bifacial HSAT technology we will reach soon bids at and below US$0.01/kWh


Let us move together to
costs below $US0.01/kWh



We're bringing together cutting-edge research and the latest trends in bifacial PV technology.

bifiPV 2020 workshops

4/5 June Hangzhou
28/29 July in San Francisco

23 April at PV conference in Budapest (2h workshop)
18 June at Intersolar in Munich (2h workshop)
12 November at PVSEC-30 in Jeju (3h session)

The demand for bifacial photovoltaic (bifiPV) workshops has been rapidly growing over the past seven years. Bringing together industry experts across continents, these workshops have proven to be critical to the development of bifacial technology. In 2020, we are hosting two workshops in two countries that are currently leading the charge in bifiPV. China's low cost, high efficiency bifacial module production and the U.S.'s large bifacial system implementation have firmly established them as key leaders in bifacial technology. Join us in Hangzhou and the San Francisco Bay Area to learn more about bifacial PV technology and project deployment and connect with industry leaders and experts.