EMS717U/EMS717P

Renewable Energy Sources

Solar photovoltaic

Content

- **Photovoltaic effect.**
- **Electrical properties of semiconductors**
- **P-N junctions**
- **Semiconductors**
- **Solar cells operating parameters**
- **Ideal solar cell performance**
- **Performance loss mechanisms**
- **PV module and PV systems**
- **Types of solar cell materials and technologies**
- **Environmental, economic and social impacts**

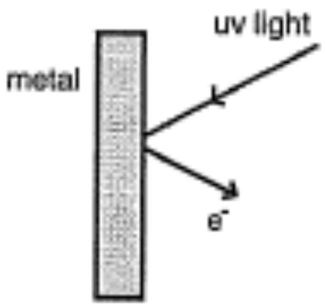
The photovoltaic effect

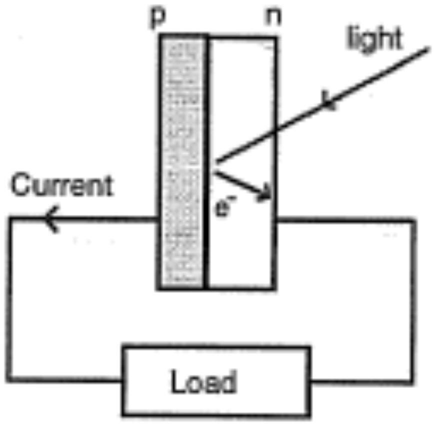
The photovoltaic effect was first observed in 1839.

Exposing materials to light produced an electric current.

This is now the basis of operation for solar cells

A.E. Becquerel, 1820-1891



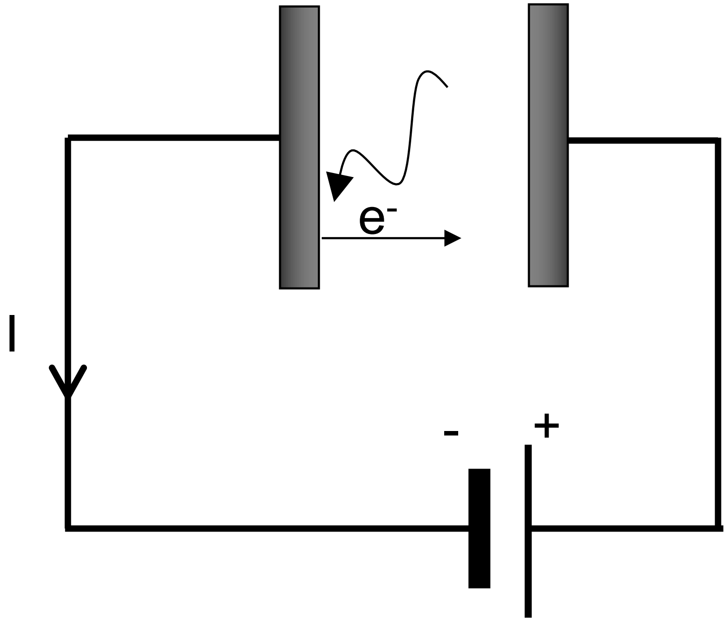


The photovoltaic effect

The photovoltaic effect was first observed in 1839. Exposing materials to light produced an electric current. This is now the basis of operation for solar cells

A.E. Becquerel, 1820-1891

Classical Photoelectric effect experiment



- Solid is illuminated with an external field present in circuit.
- For low frequency radiation there is no current.
- As the photon energy increases, a current proportional to photon flux is measured.

Note: The experiment is not useful for energy conversion for converting photons to electric power as an external field is needed.

Semiconductor devices allow internal field to be established.

Types of solar cell materials

Solar cell production dominated by silicon solar cell technologies of mono-Si, poly-Si and a-Si which amount to around 90% of the market

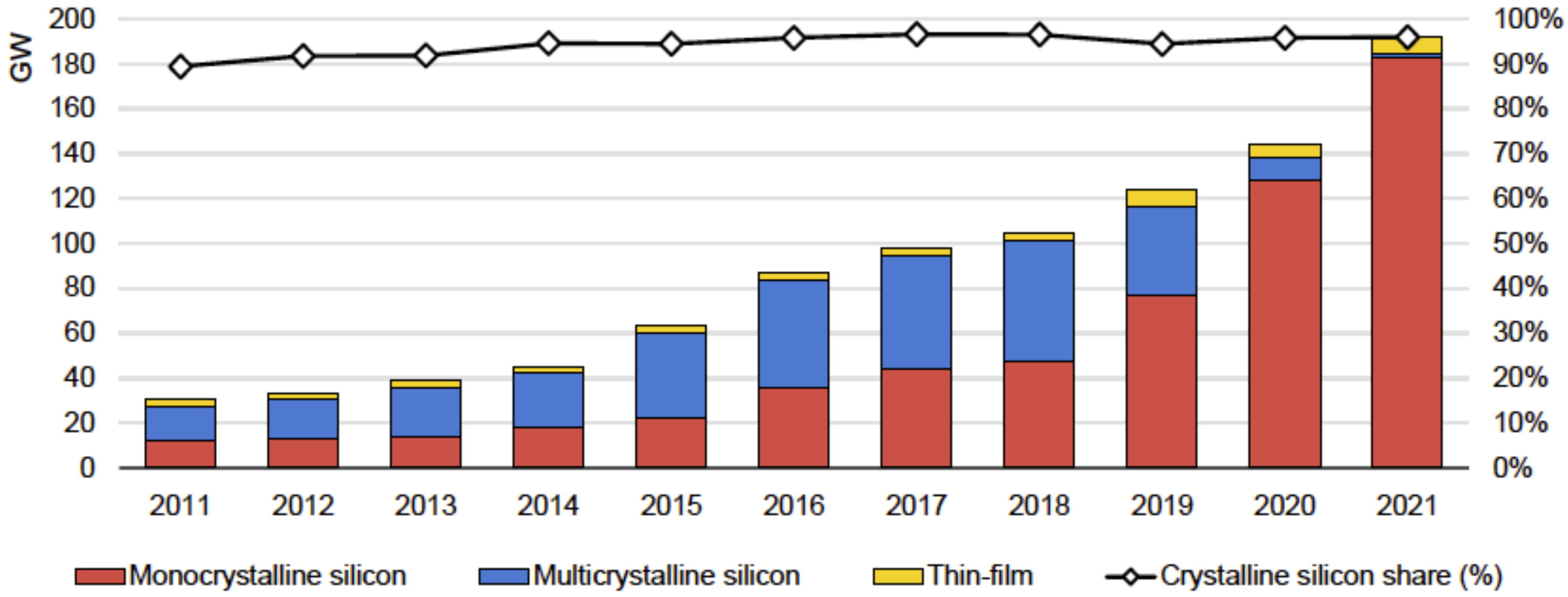
In addition to the established crystalline silicon cell technologies, there are advanced thin film technologies of cadmium Telluride (CdTe), copper indium diselenide (CIS), amorphous silicon (a-Si) and thin film silicon (thin film-Si). In these processes the active material is grown directly on the substrate which simplifies the process and reduces cost

Amorphous silicon is in commercial production but the other thin film technologies are at the research stage – however, due to reduced manufacturing costs are expected to gain more market share in future.

Types of solar cell materials

Two main technologies currently dominate global solar PV markets and supply chains: crystalline silicon (c-Si) modules account for over 95% of global production while cadmium telluride (CdTe) thin-film PV technology makes up the remaining.[1]

Solar PV module production by technology, 2011-2021

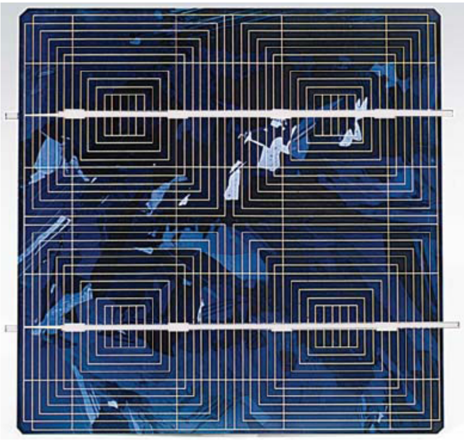


Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Photovoltaic module systems

PV cells are largely based on semiconducting silicon materials such as monocrystalline silicon (mono-Si), polycrystalline Si (poly-Si) and amorphous Si (a-Si).

The silicon wafers are fabricated into solar cells using semiconductor industry processes and multiple identical cells are connected and encapsulated together to form a module.



Example of crystalline silicon solar cell

Crystalline silicon 64 cell PV module

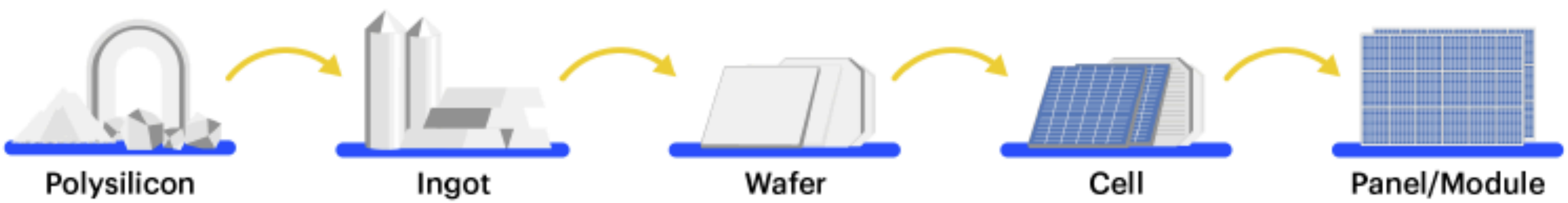
Multiple module PV array

PV systems are based on PV module units and rated on the power output under Standard Testing Conditions (STC) of $1kW/m^2$ of AM1.5 irradiance and cell temperature of 25ºC.

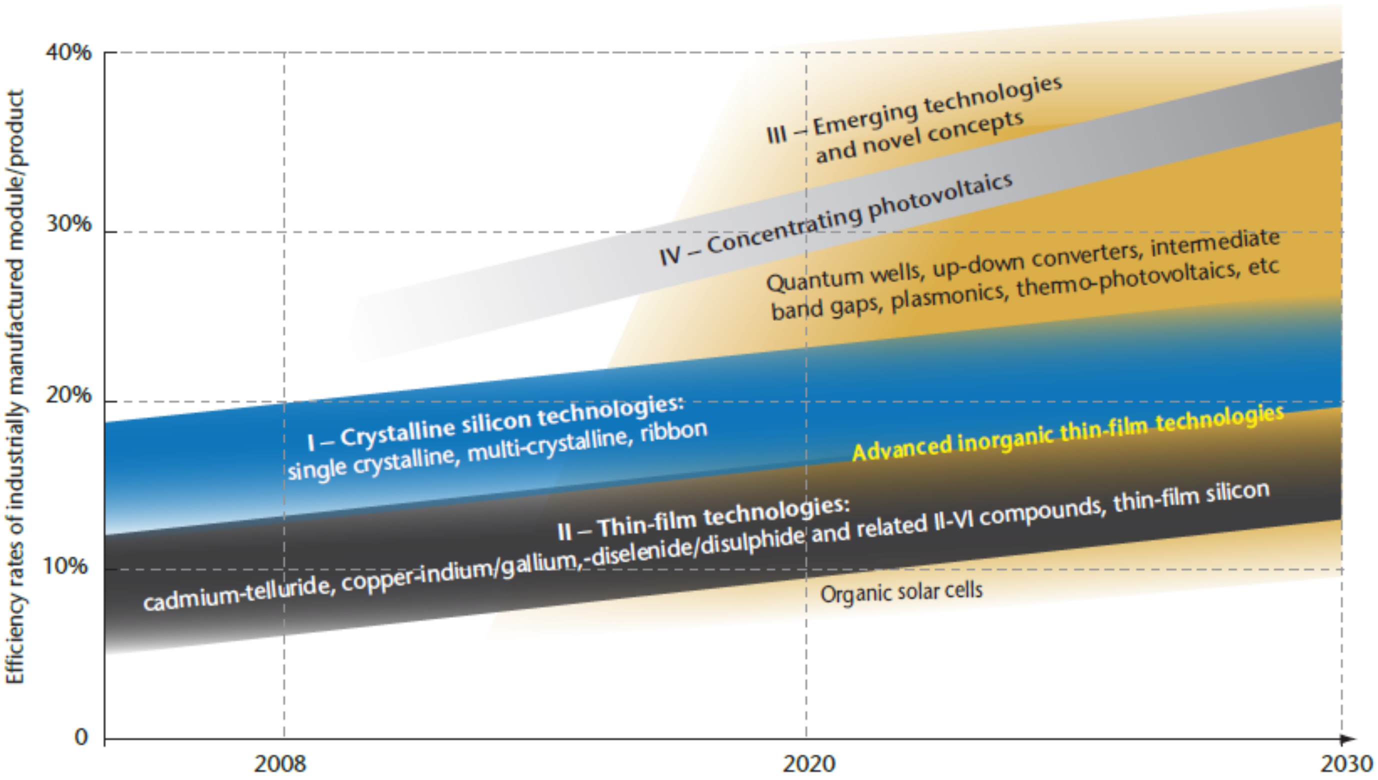
The PV module output under STC is expressed as “peak Watt” or W_p nominal capacity.

Key PV manufacturing processes by segment

Segment	Key processes
Polysilicon	Silicon purification
Ingots	Crystalline ingot growing; material property analysis; ingot cutting
Wafers	Wiring; pre-washing; wafer separation; main washing; wafer inspection and sorting
Cells	Wet station; diffusion; chemical vapour deposition (CVD)/sputtering; screen printing; baking; cell transfer; inspection
Modules	Cell wiring (string); layup (module assembly); laminating and sealing; curing; frame and terminal assembly; module transfer; inspection



Photovoltaic technology status and prospects



Source: IEA PVPS.

***KEY POINT**: Current technologies will co-exist with emerging technologies and novel concepts.*

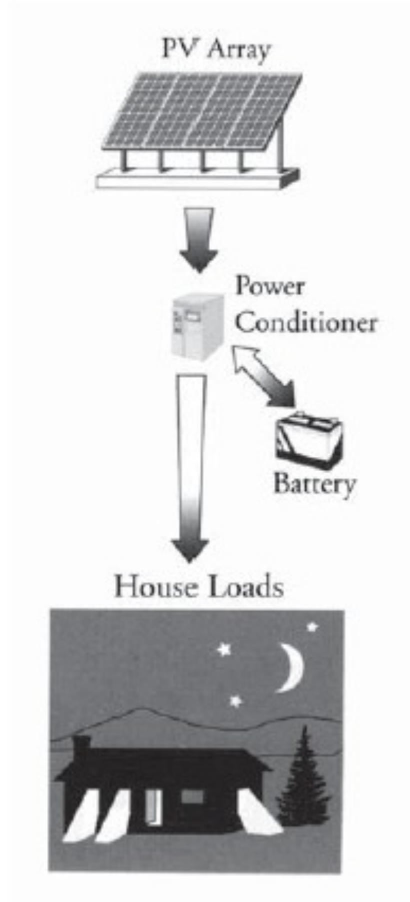
PV systems

PV installation components

PV modules are then combined with other components (dependent on specific application) to constitute the “balance of systems” or BOS.

BOS components are categorized as:

- **Solar Cell** – for conversion of solar radiation into electrical power
- **Batteries** – as energy storage to meet demand at night or on overcast days
- **Inverters** – required to convert DC to AC power
- **Controllers** – to manage energy storage to battery and deliver power to the load
- **Structure** – required to mount or install the PV modules and other components



Example BOS for off-grid domestic power

Note: Not all systems require all these components, e.g., on-grid systems do not require batteries as the grid acts as energy storage medium

PV systems

Grid-Connected PV Systems

These include large scale PV power plants

Example: 20 MW peak DC power station in Beneixaxa, Spain

Consists of 100,000 polycrystalline solar cells covering an area of 500,000 sqm

154 MW Swan Hill plant in Australia

Also include widely distributed roof top mounted PV systems for municipal and domestic building applications

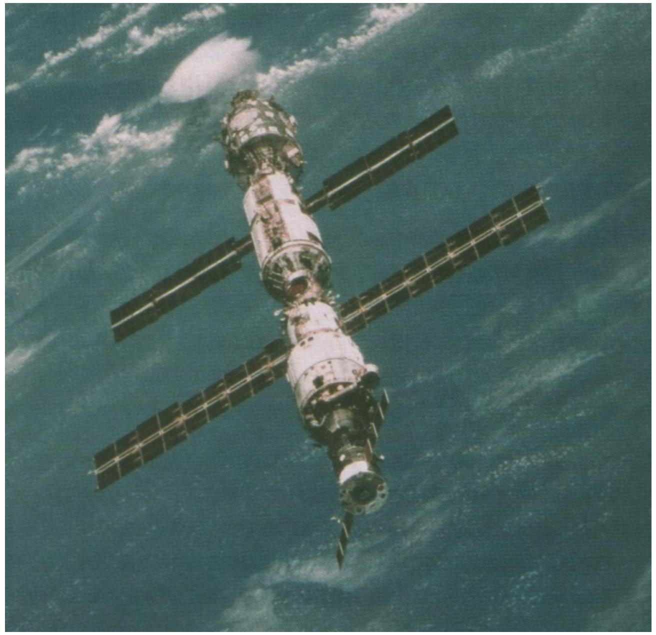
PV systems

Off-grid PV Systems

Broad range of application and size

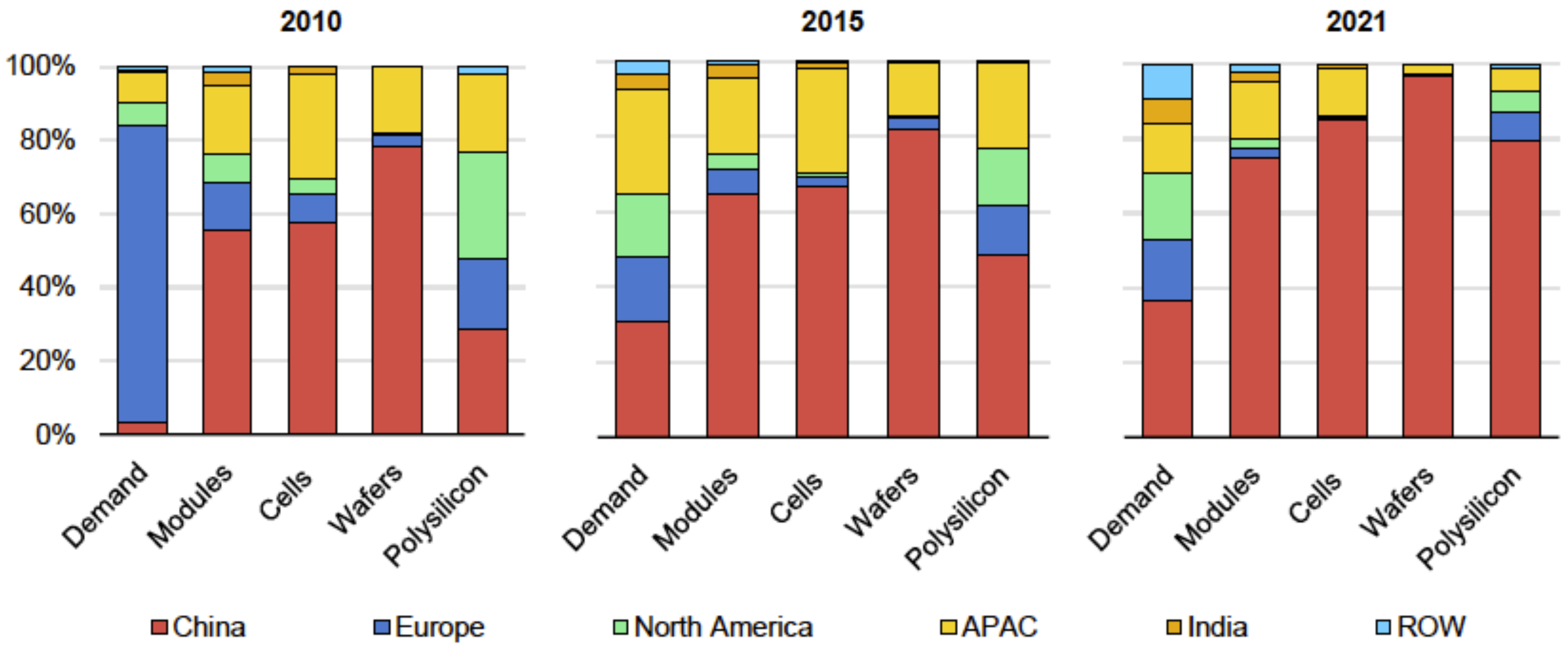
Example systems

a) International Space Station powered by 110 kW array, and smaller scale applications as
b) parking meter
c) navigation buoy
d) telemetry system



Solar PV manufacturing capacity

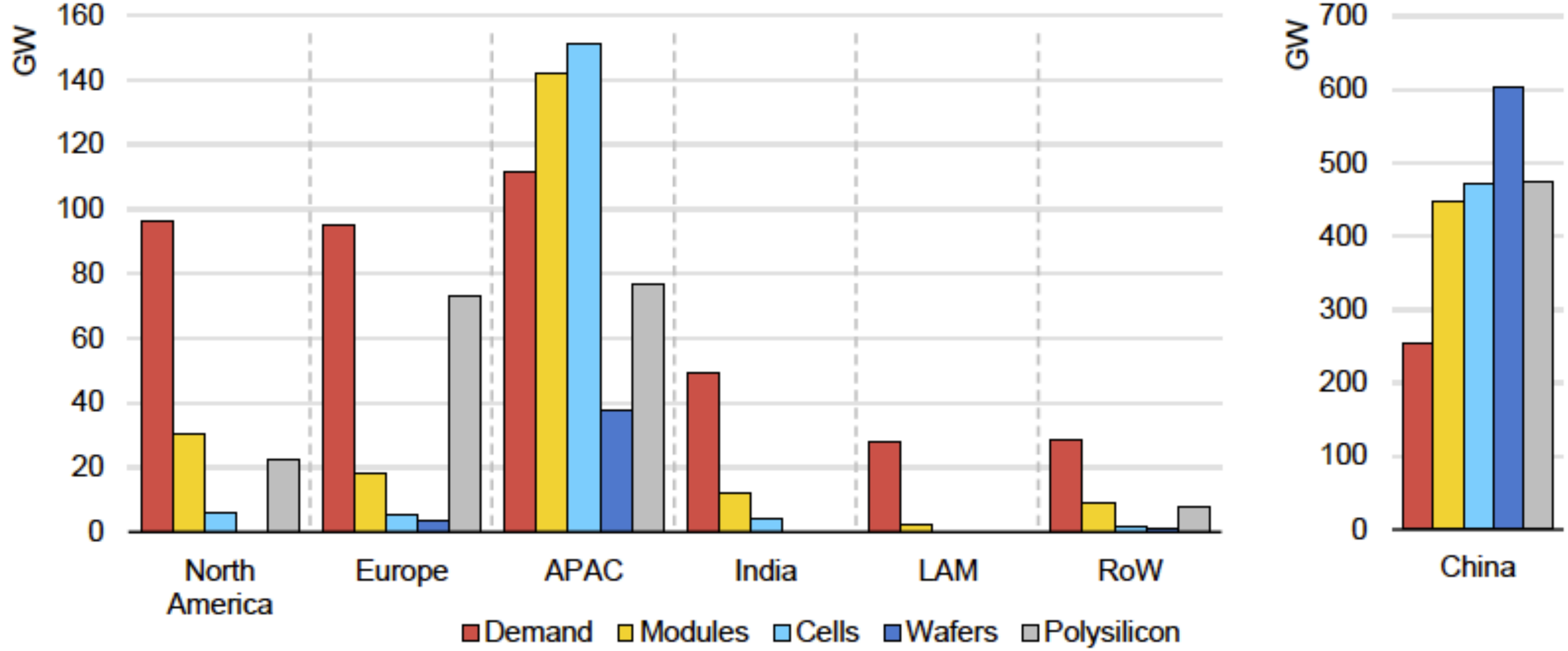
Solar PV manufacturing capacity by country and region, 2010-2021



Notes: APAC = Asia-Pacific region excluding India. ROW = rest of world.

Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

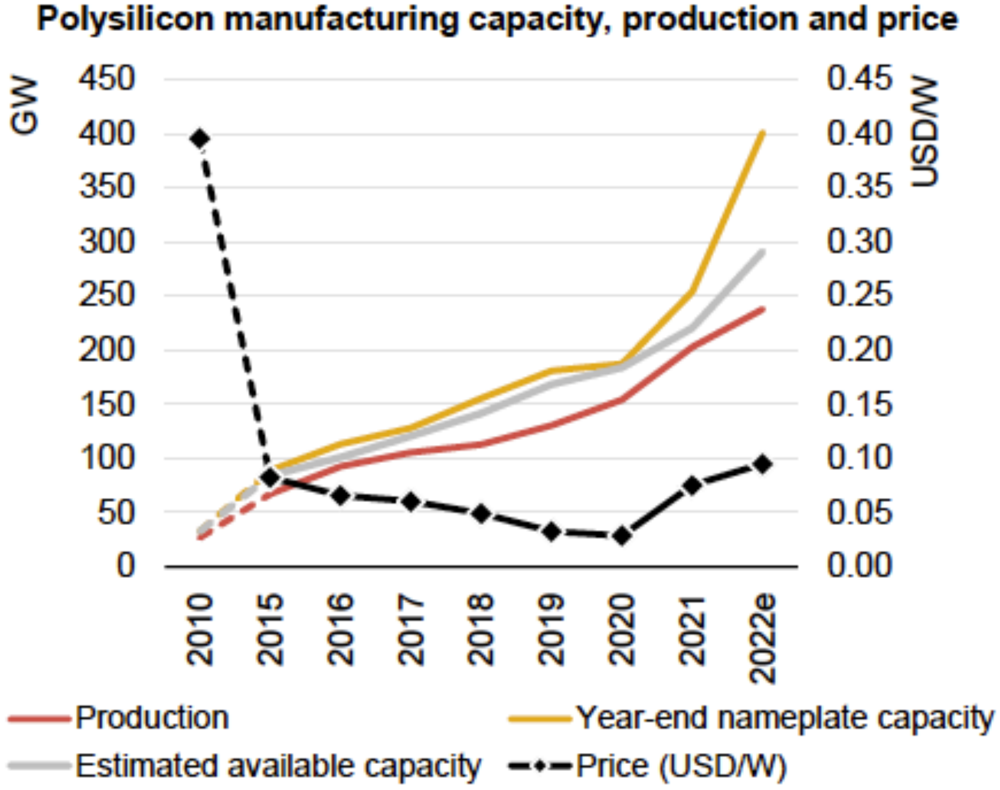
Cumulative solar PV production and demand, 2017-2021

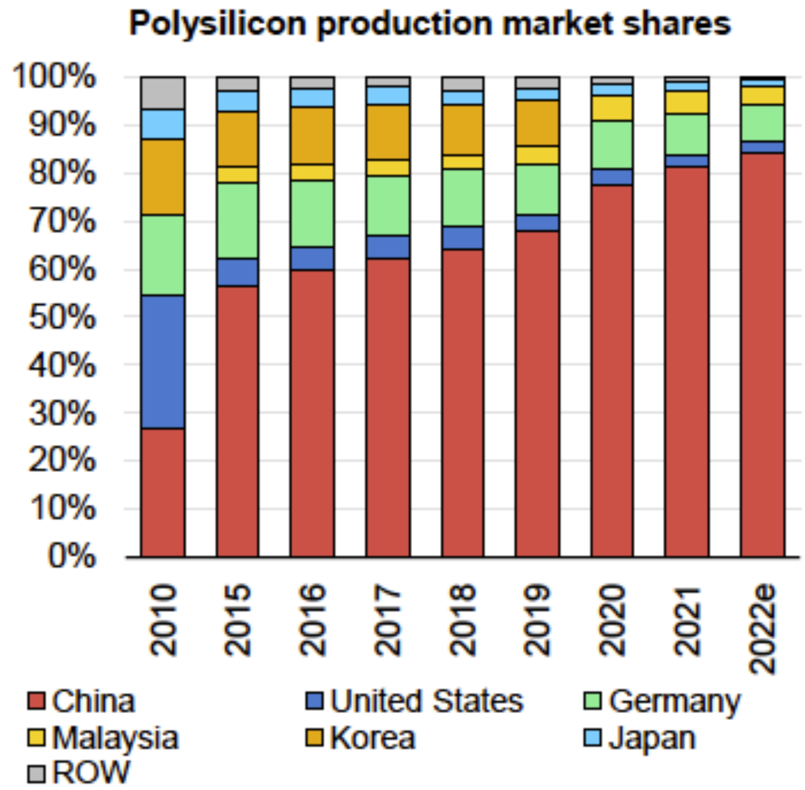


Note: APAC = Asia-Pacific region excluding India.

Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Global polysilicon manufacturing capacity, production, average price and market shares, 2010-2022

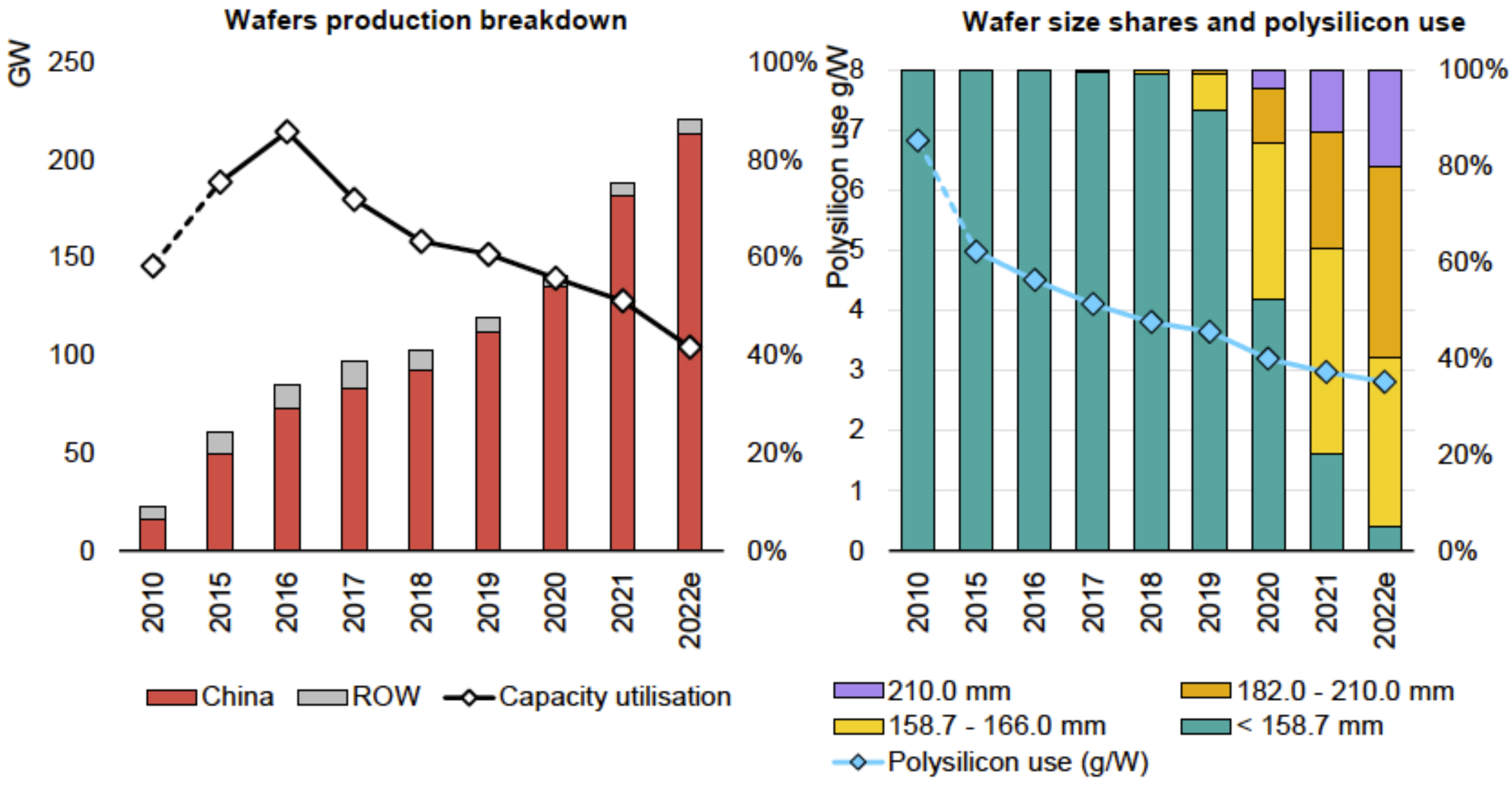




Note: ROW = rest of world.

Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

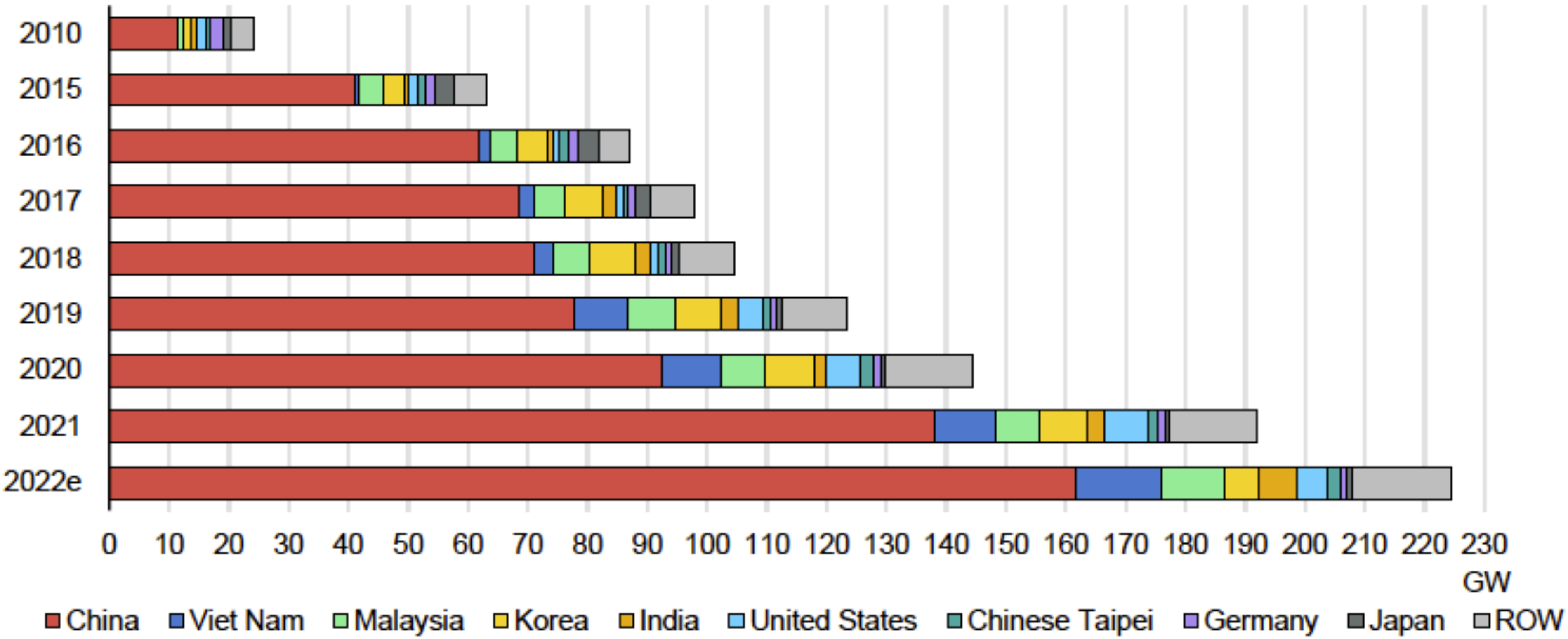
Global PV wafer production and capacity utilisation (left), and wafer market shares by size and average polysilicon use per watt (right), 2010-2022



Notes: ROW = rest of world. Values for 2022 are estimates.

Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation, PV InfoLink and VDMA.

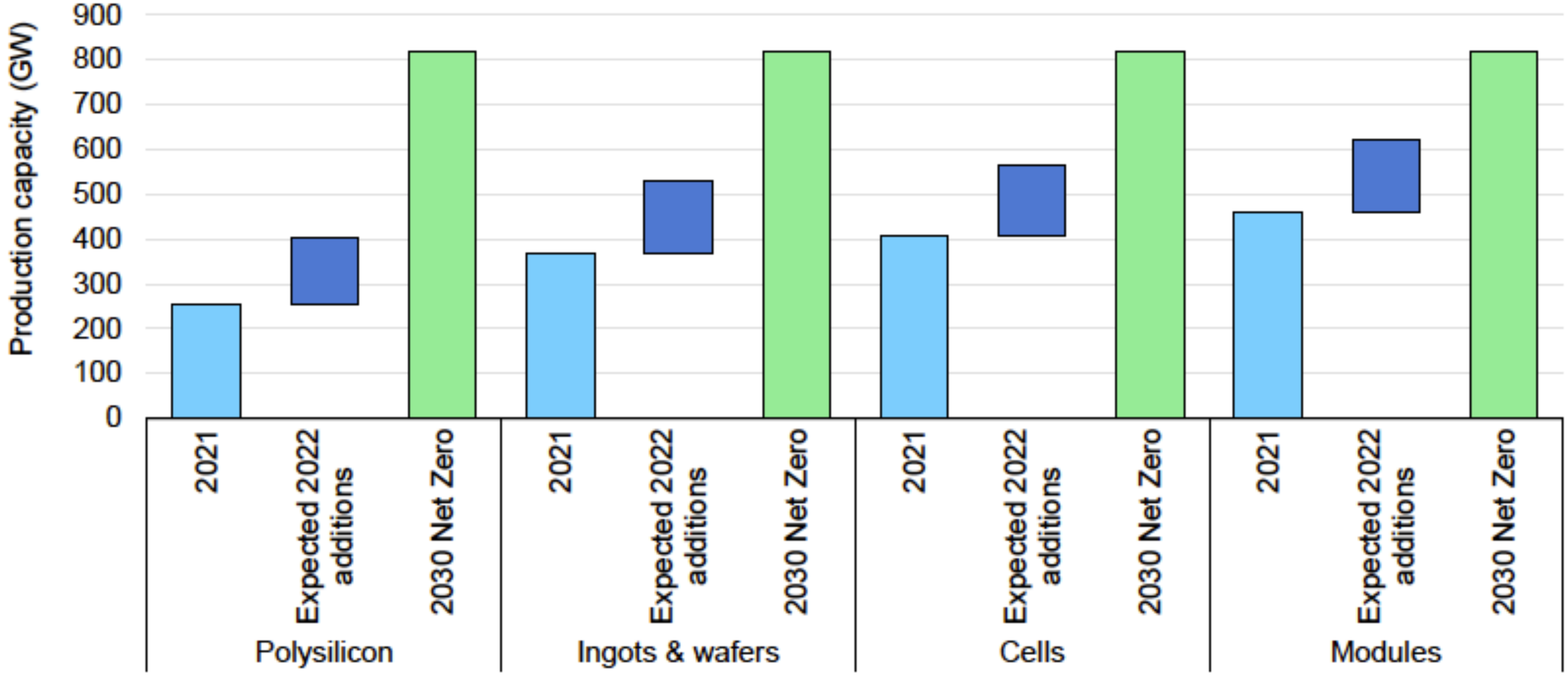
Global solar PV module production, 2010-2022



Notes: ROW = rest of world. Values for 2022 are estimates.

Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

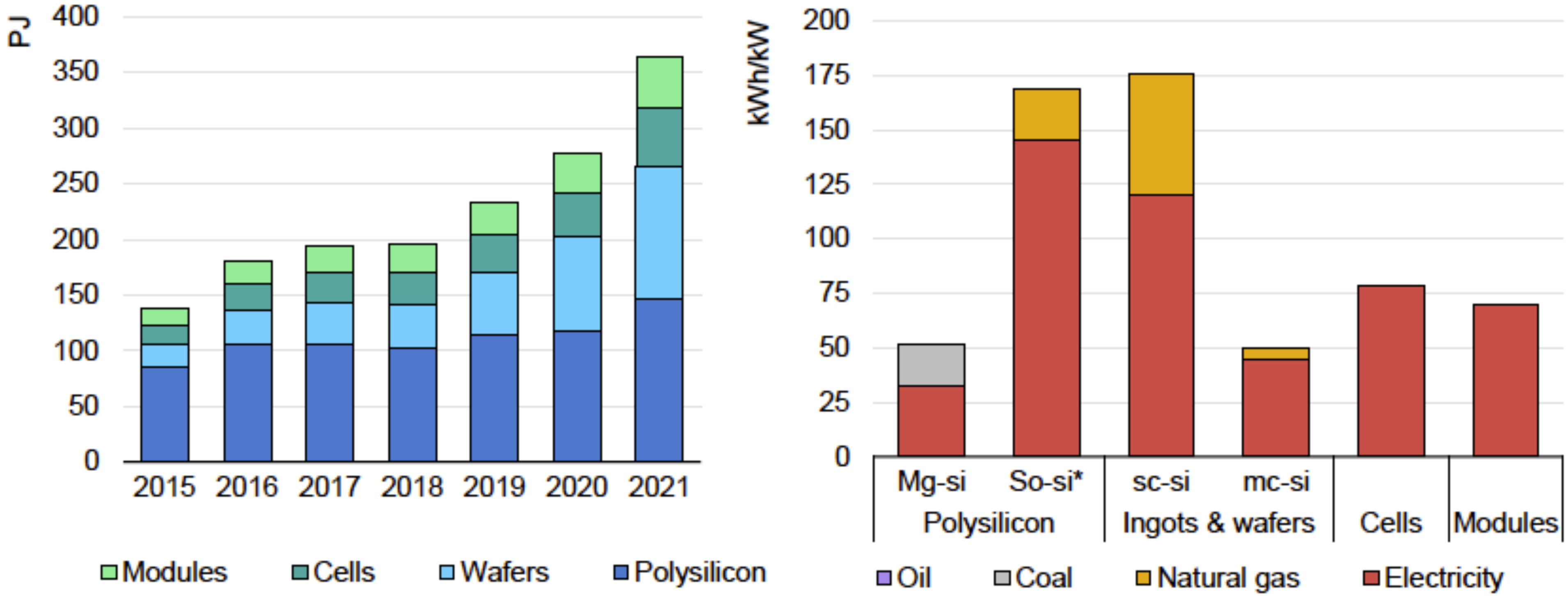
Solar PV supply chain capacity in operation and under construction, and gap to Net Zero by 2050 Scenario, 2021 to 2030



Sources: Under construction: IEA analysis based on PVPS, PV InfoLink, SPV and RTS. 2030 Net Zero: based on (IEA, 2021g), manufacturing capacity to satisfy 630 GW of annual capacity additions.

Energy consumption of solar PV manufacturing

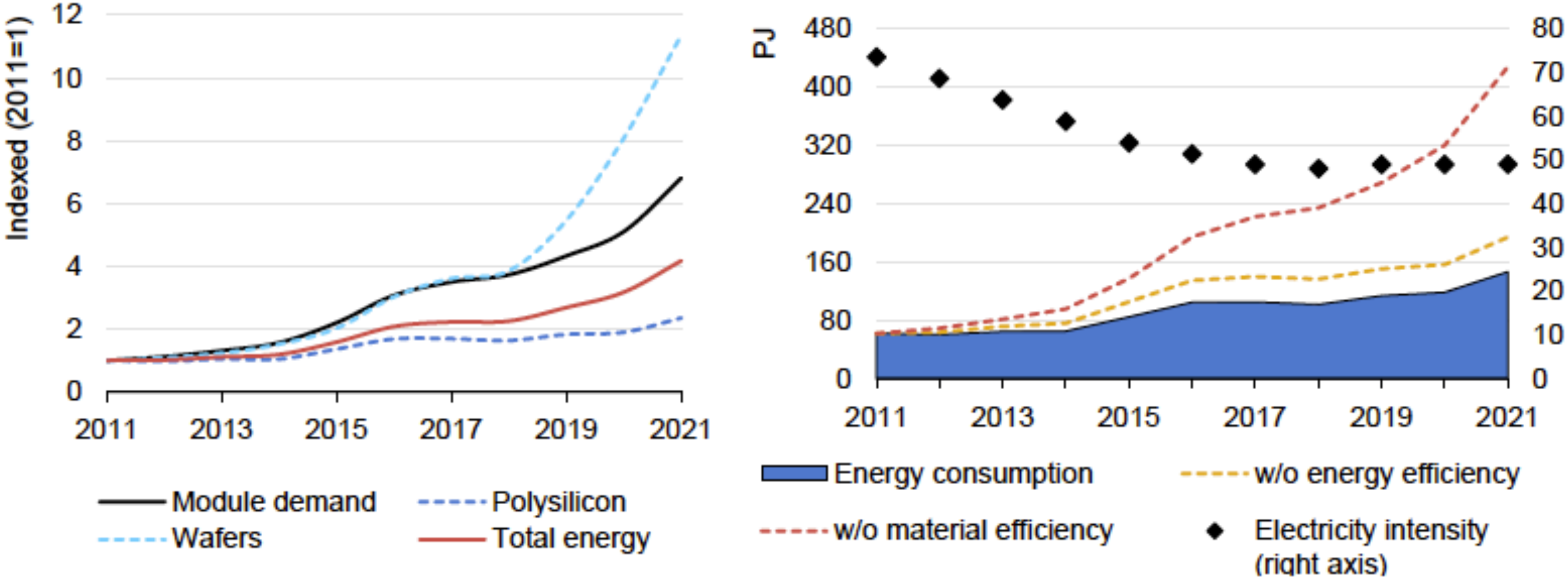
Energy consumption of solar PV manufacturing by segment, 2015-2021 (left), and energy intensity per segment (right)



Notes: Mg-si = metallurgical-grade silicon. So-si* = solar-grade silicon using the Siemens process. sc-si = monocrystalline wafers. mc-si = multicrystalline wafers.

Source: Right graph: IEA-PVPS (2020).

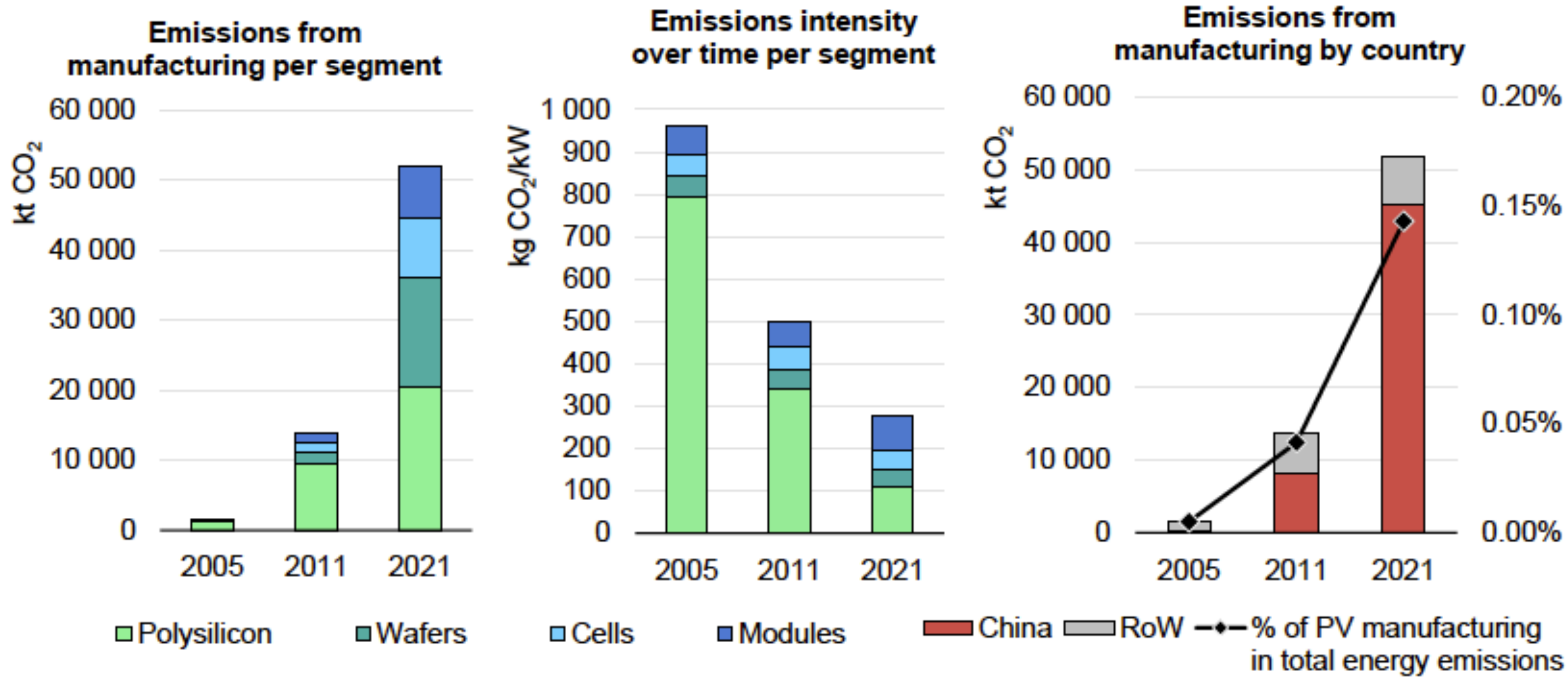
Global energy consumption for solar PV manufacturing and module production (left) and polysilicon energy savings since 2011 (right)



Source: Frischknecht et al. (2020).

Emissions from solar PV manufacturing

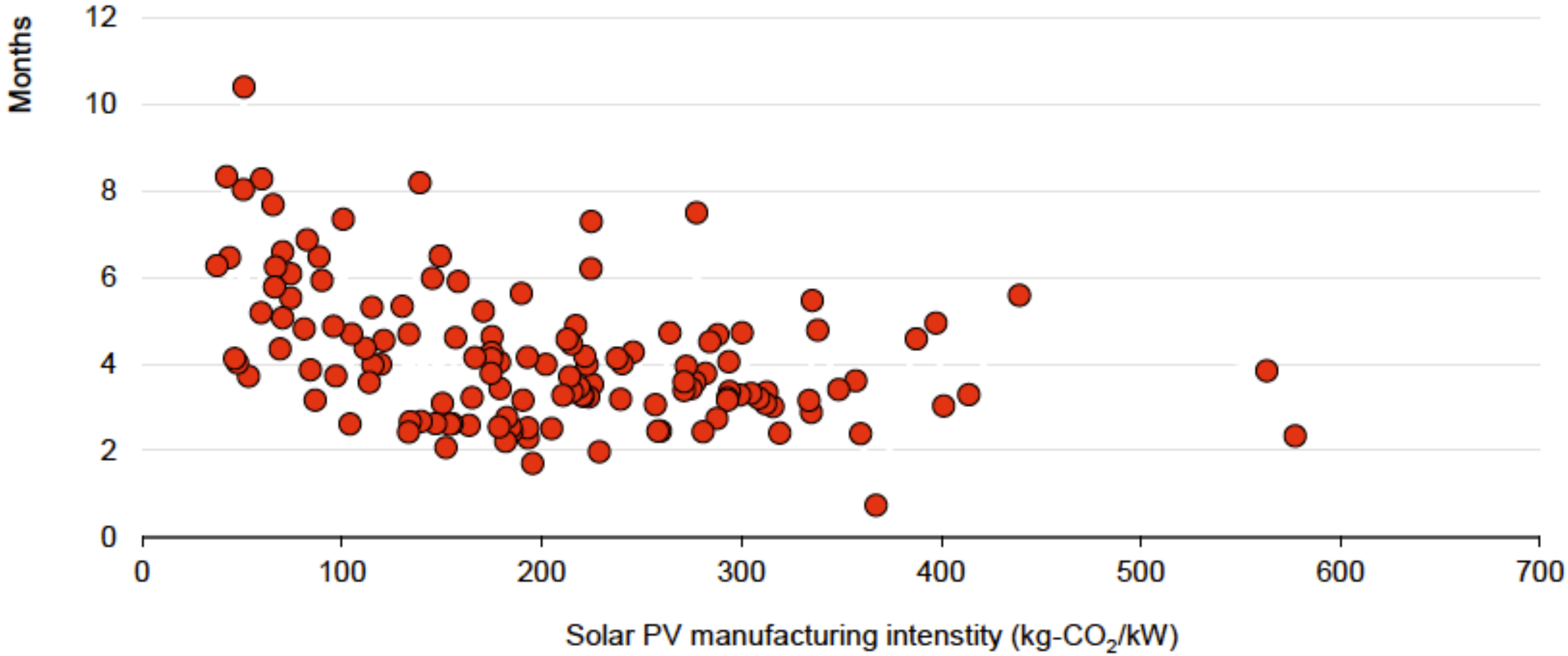
Absolute emissions and emission intensity of PV manufacturing globally



Notes: RoW = rest of world. This report does not consider emissions derived from manufacturing intermediate products involved in PV module assembly (glass, cables, etc.). Total energy emissions refers to CO_2 emissions from energy combustion and industrial processes.

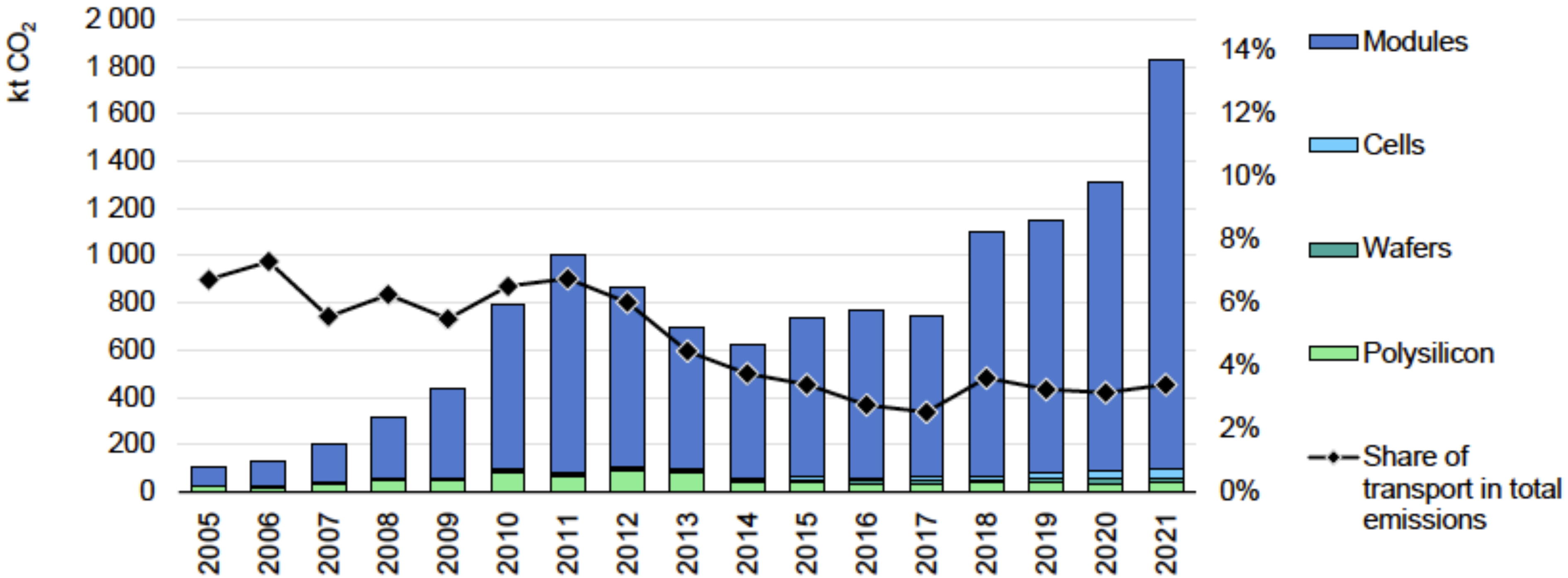
Sources: Right graph: IEA (2021a; 2022d). Left graph: IEA (2021a). IEA analysis also based on BNEF (2022a), PVPS, InfoLink and UN Comtrade.

Solar PV manufacturing emissions intensity and payback period



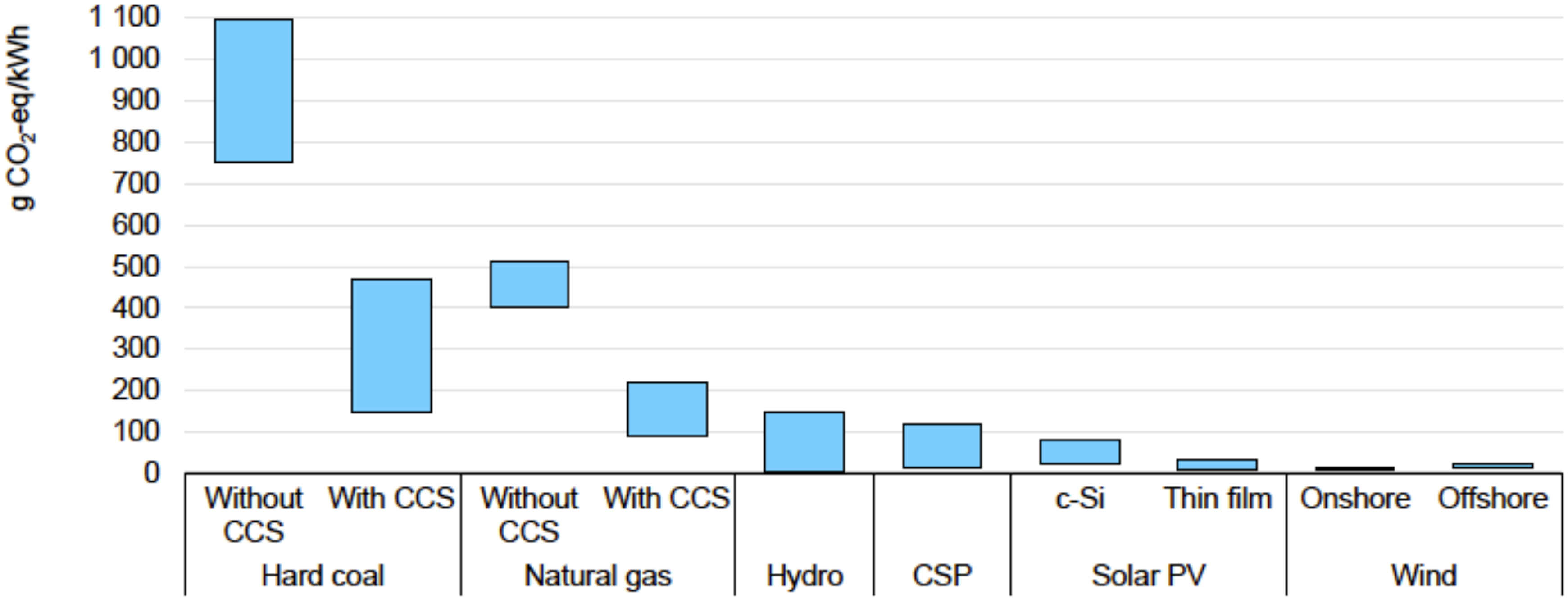
Notes: Each data point represents a country. The analysis assumes that renewable electricity generation from solar PV capacity displaces fossil fuels in the electricity mix, based on their current share.

Absolute CO_2 emissions associated with transport of PV components



Sources: IEA (2022a). IEA analysis also based on BNEF (2022a), PVPS, InfoLink and UN Comtrade.

Lifecycle GHG emissions ranges for selected sources of electricity, 2020

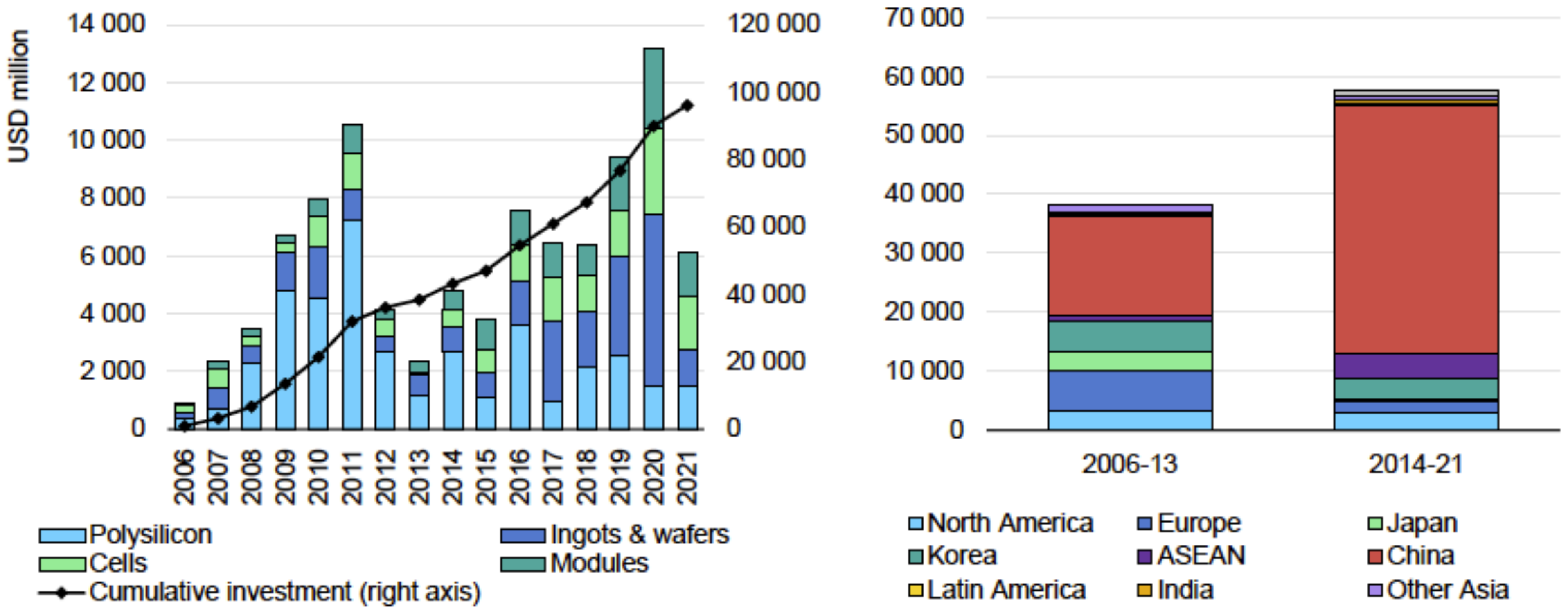


Notes: CCS = carbon capture and storage. CSP = concentrated solar power. Ranges reflect regional variations.

Source: UNECE (2021) calculations based on data from Hertwich et al. (2016), Gibon et al. (2017) and Wernet et al. (2016). UNECE (2021) adapted these datasets based on recent scientific literature, technical reports and expert consultation.

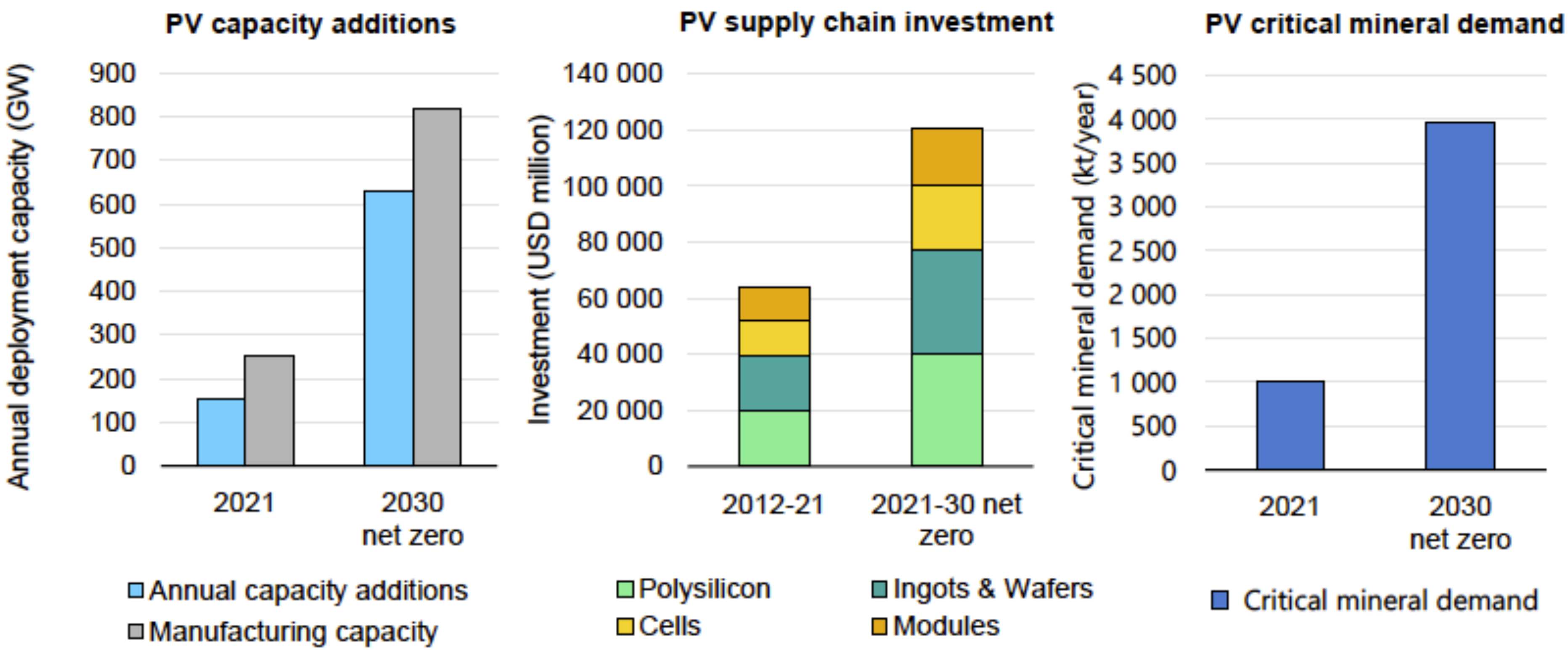
Investments for solar PV manufacturing

Solar PV manufacturing facility investment by segment (left) and by country/region (right), 2006-2021



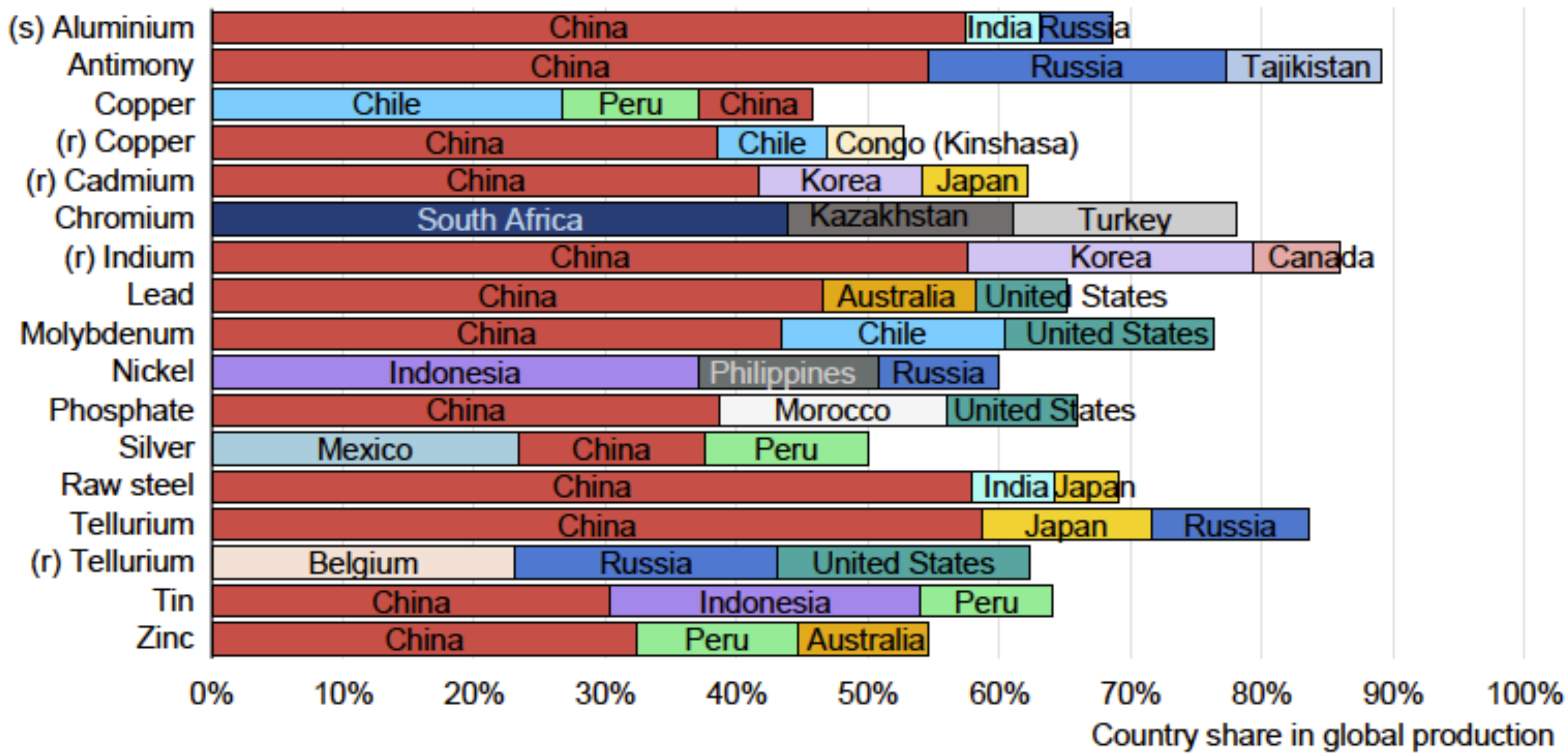
Notes: ASAEN = Association of Southeast Asian Nations. Investment numbers are associated with the manufacturing facilities' commissioning dates. The partial commissioning of large plants is taken into account.

Solar PV capacity additions (left), supply chain investment (centre) and mineral demand (right), 2021 and 2030 under the IEA Net Zero by 2050 Scenario



Sources: Left graph: IEA (2021f). Centre graph: IEA analysis based on BNEF (2022b), PVPS, PV InfoLink, SPV and RTS PV. Right graph: IEA (2021d).

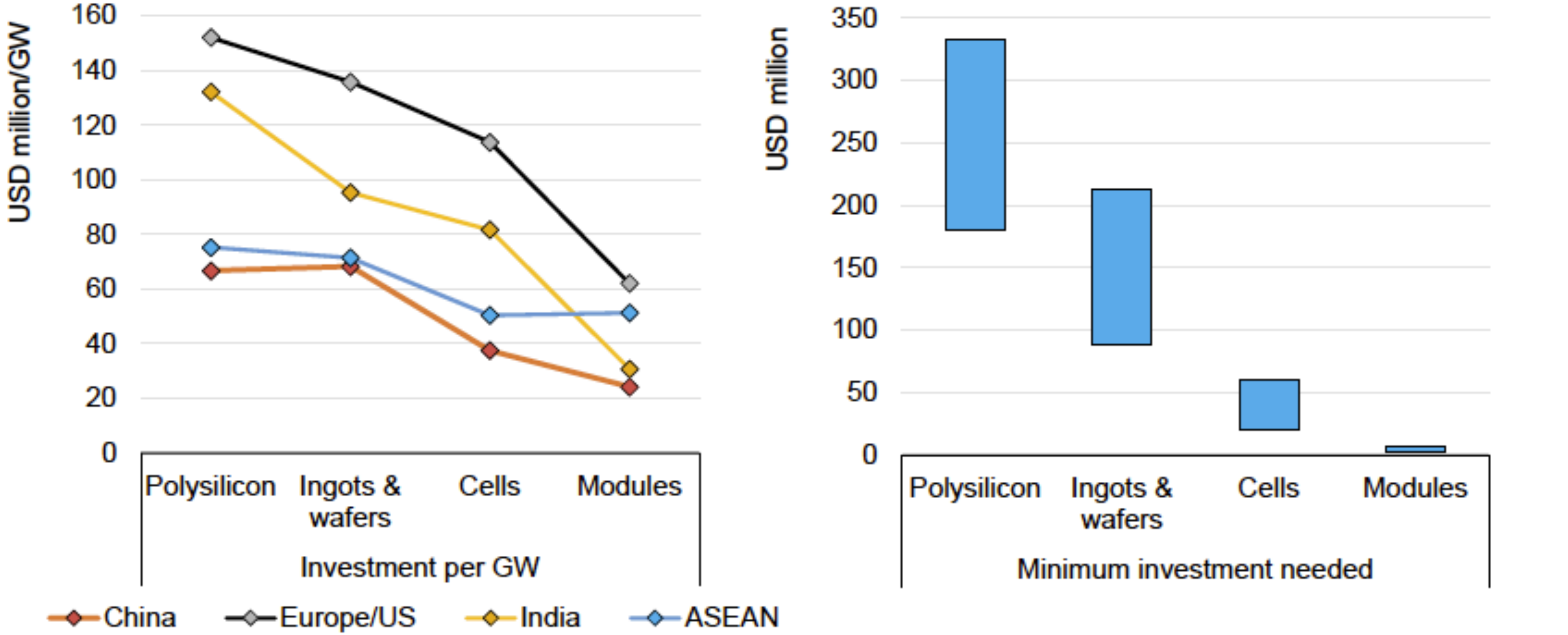
Top three producing countries' shares in global production of selected minerals used for solar PV manufacturing, 2021



Notes: (s) = smelter production. (r) = refinery production. Other values correspond to mine production.

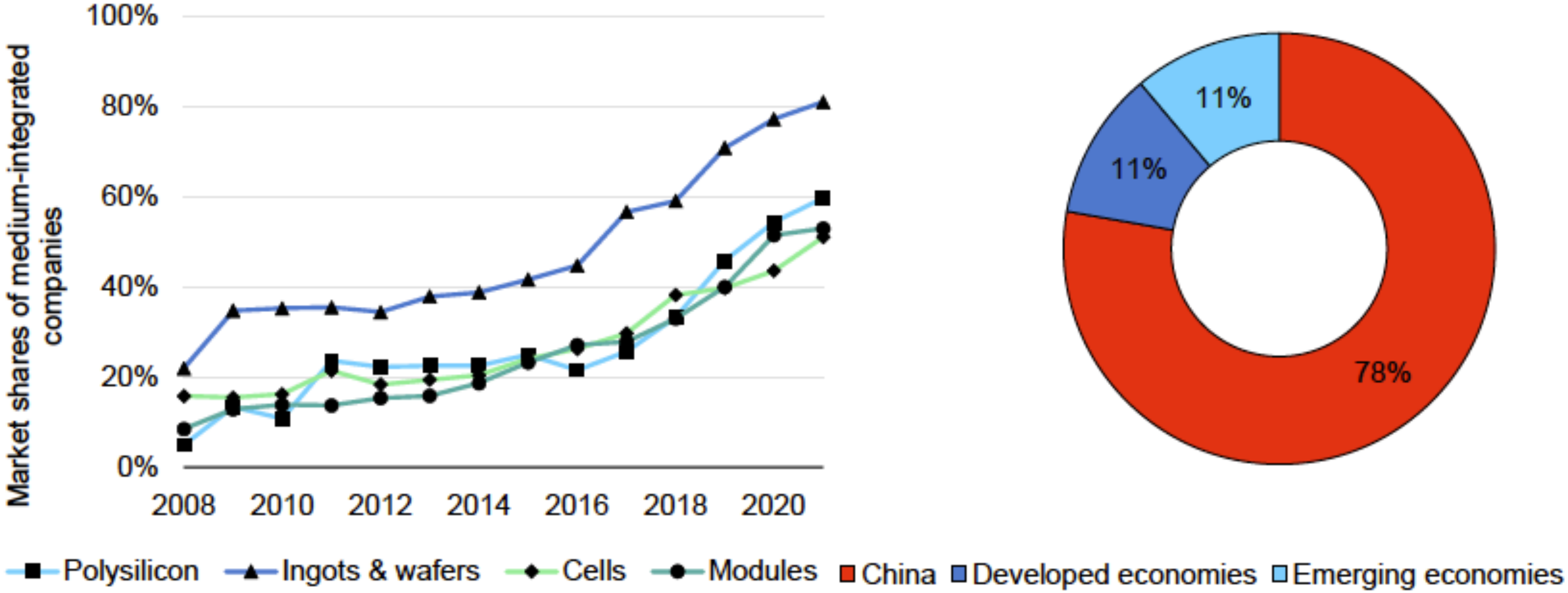
Source: USGS (2022).

Investment costs (left) and minimum investment requirements (right) by PV manufacturing segment



Notes: ASEAN = Association of Southeast Asian Nations. Investment costs are based on investment estimates announced by companies for more than 100 manufacturing projects in various supply chain segments. For countries that do not have any commissioned manufacturing facilities for certain supply chain segments, data from feasibility projects or estimates were used.

Integrated solar PV manufacturer market shares by supply chain segment (left) and by country/region (right)



Note: A vertically integrated company manufactures products in at least three segments of the PV supply chain. Of the 62 integrated companies at present, 49 are in China.

Conversion efficiency and price

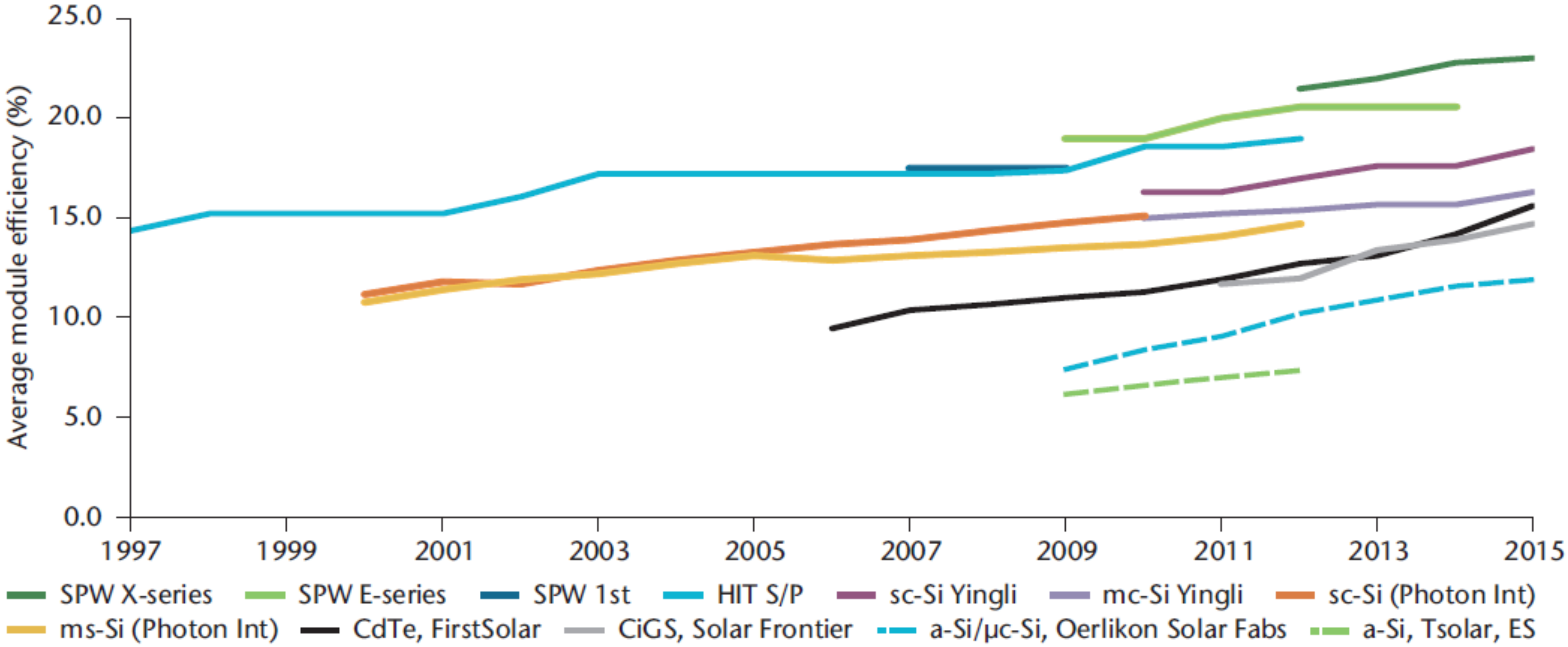
Conversion efficiency

Typical conversion efficiency (solar energy to electrical energy) for silicon solar cells are between 11 – 15%.

Efficiency >30% demonstrated in laboratory tests – however, commercial modules only demonstrate ~ half that efficiency

This is due to differences in production procedure between lab and industry

Commercial module efficiencies (actual and expected)



Note: SPW stands for *SunPower*, HIT S/P stands for *Heterojunction Intrisic Thin layer Sanyo/Panasonic*.

Source: De Wild-Scholten, M. (2013), "Energy payback time and carbon footprint of commercial PV systems", *Solar Energy Materials & Solar Cells*, No. 119, pp. 296-305.

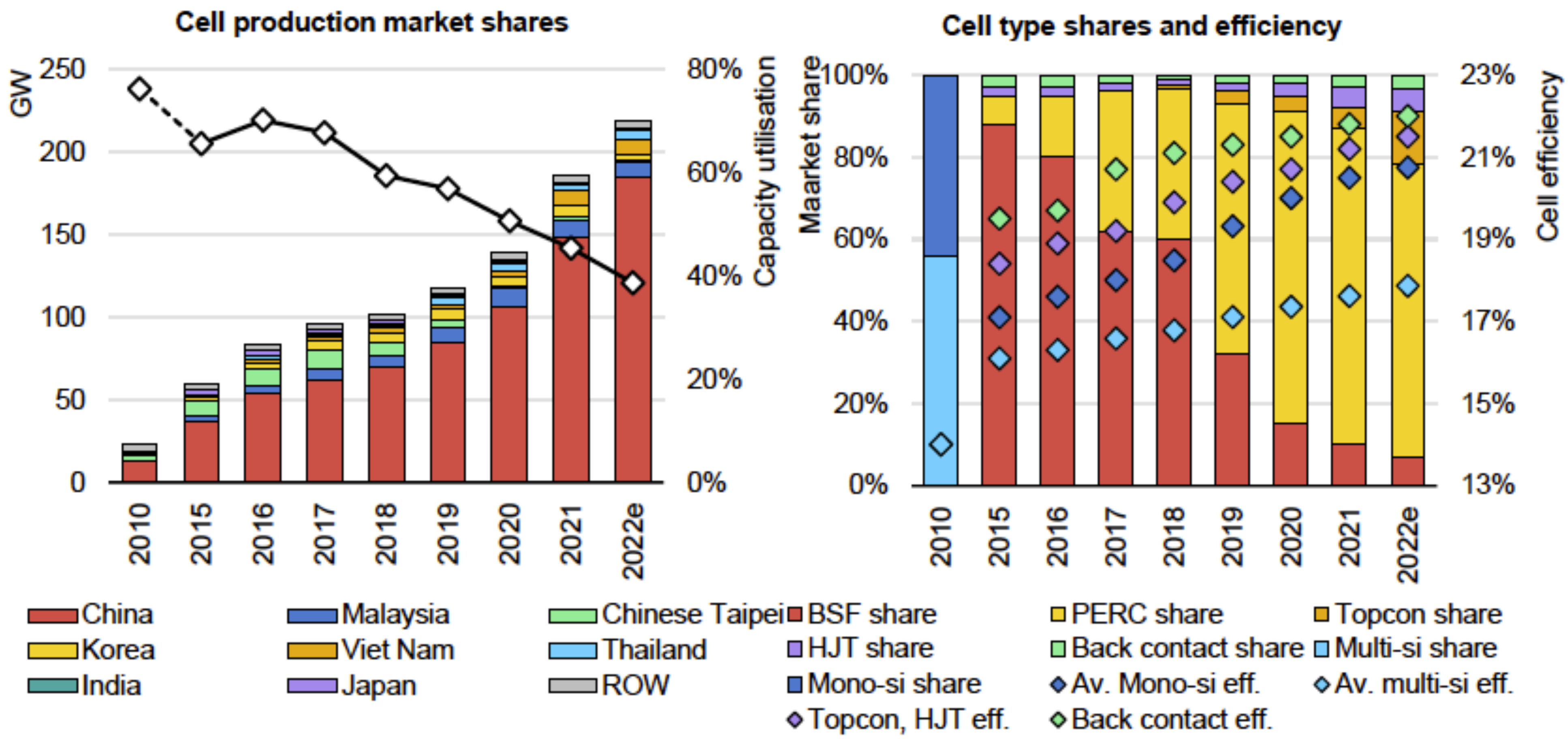
KEY POINT: PV efficiencies have been rising constantly, and still have room for improvement.

General technology target

Table 8: General technology target

Targets (rounded figures)	2008	2020	2030	2050
Typical flat-plate module efficiencies	Up to 16%	Up to 23%	Up to 25%	Up to 40%
Typical maximum system energy pay-back time (in years) in 1500 kWh/kWp regime	2 years	1 year	0.75 year	0.5 year
Operational lifetime	25 years	30 years	35 years	40 years

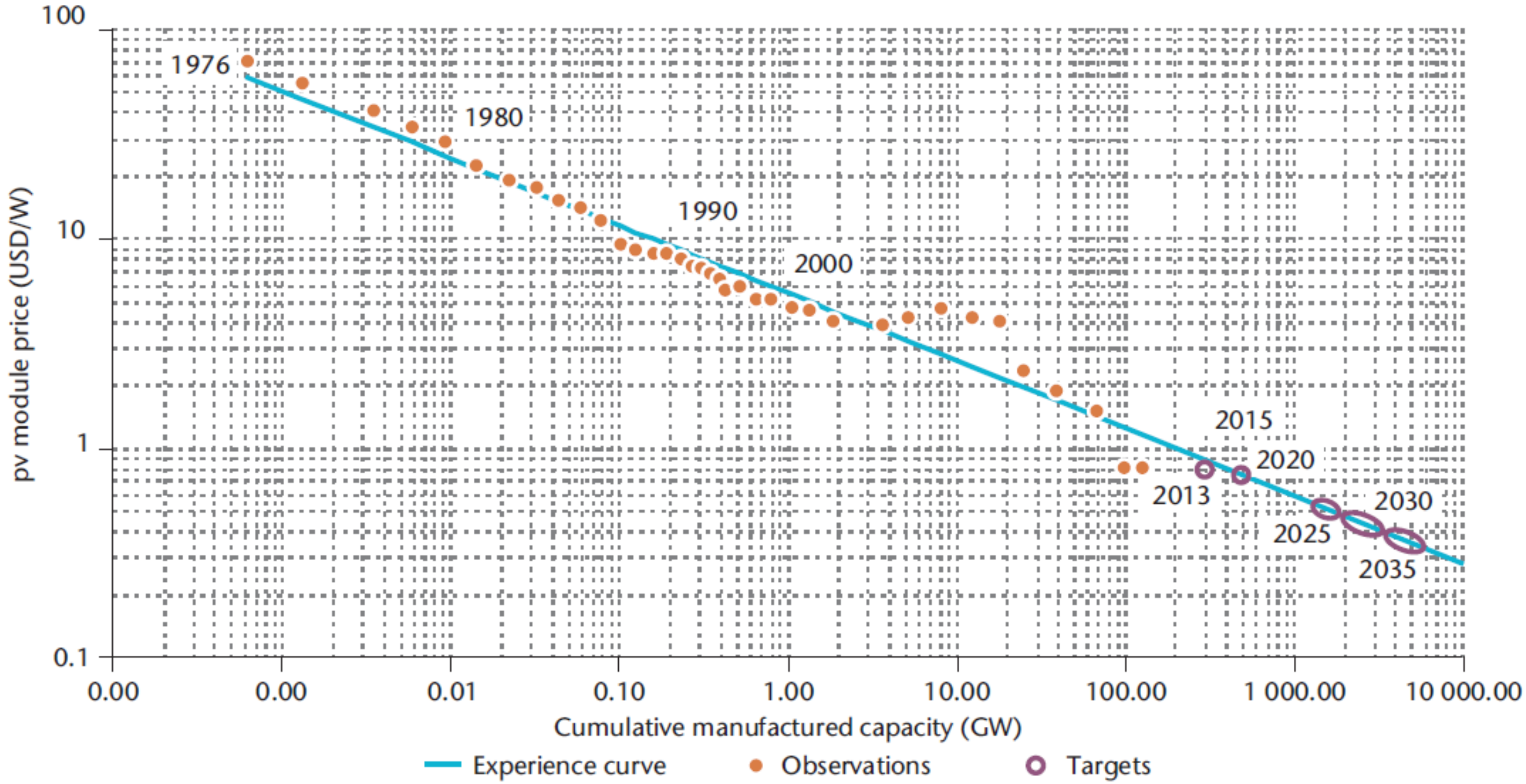
Global PV cell production and manufacturing capacity utilisation (left), and market shares and module efficiency by cell type (right), 2010-2022



Notes: ROW = rest of world. BSF = back surface field. HJT = heterojunction. PERC = Passivated Emitter and Rear Cell.

Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation, PV InfoLink and VDMA.

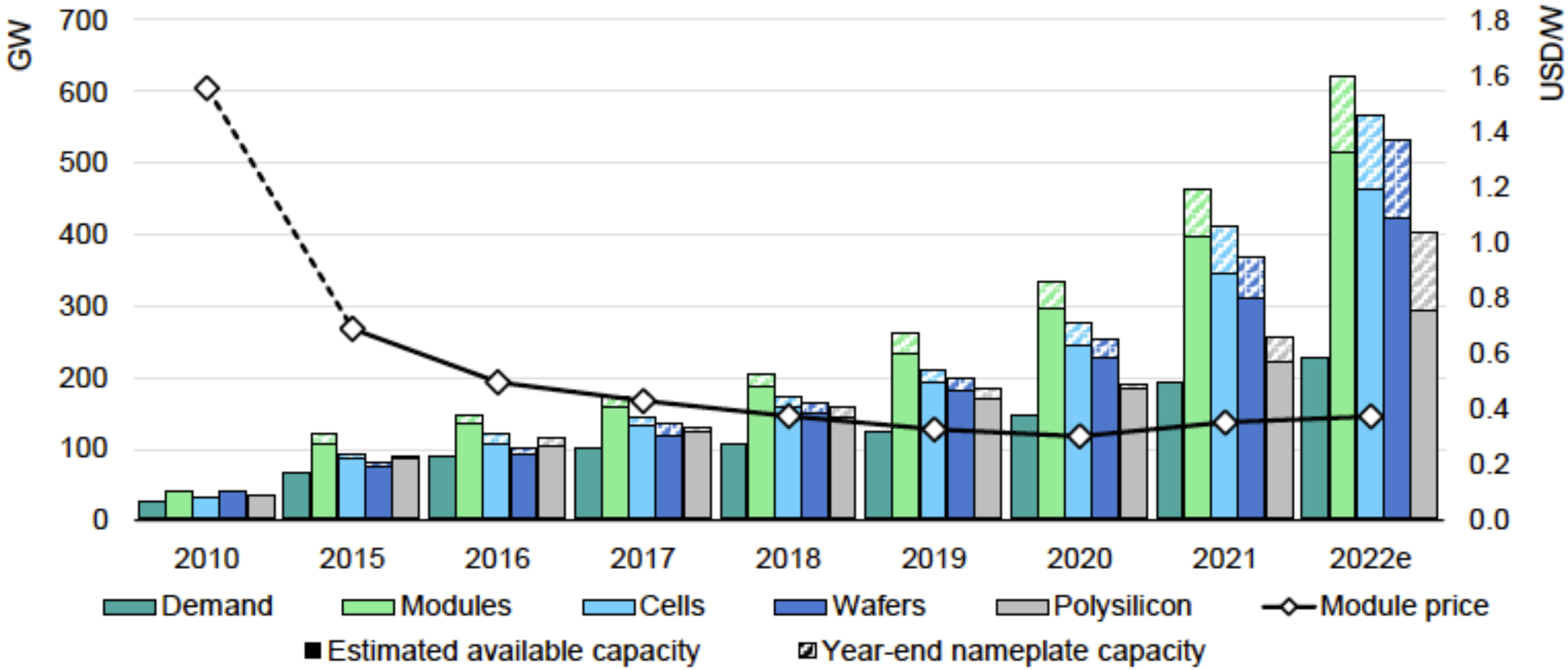
Past modules prices and projection to 2035 based on learning curve



Notes: Orange dots indicate past module prices; purple dots are expectations. The oval dots correspond to the deployment starting in 2025, comparing the 2DS (left end of oval) and 2DS hi-Ren (right end).

KEY POINT: This roadmap expects the cost of modules to halve in the next 20 years.

Global PV manufacturing capacity, demand and average module selling price, 2010-2022

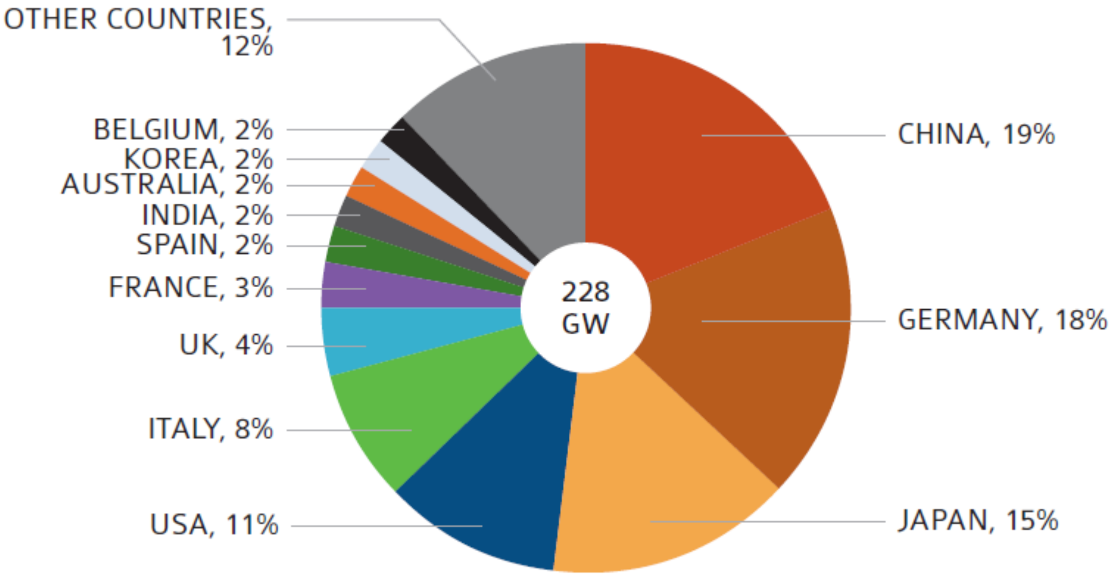


Note: Module price reflects all-in global average price for all solar PV technologies. Values for 2022 are estimates.

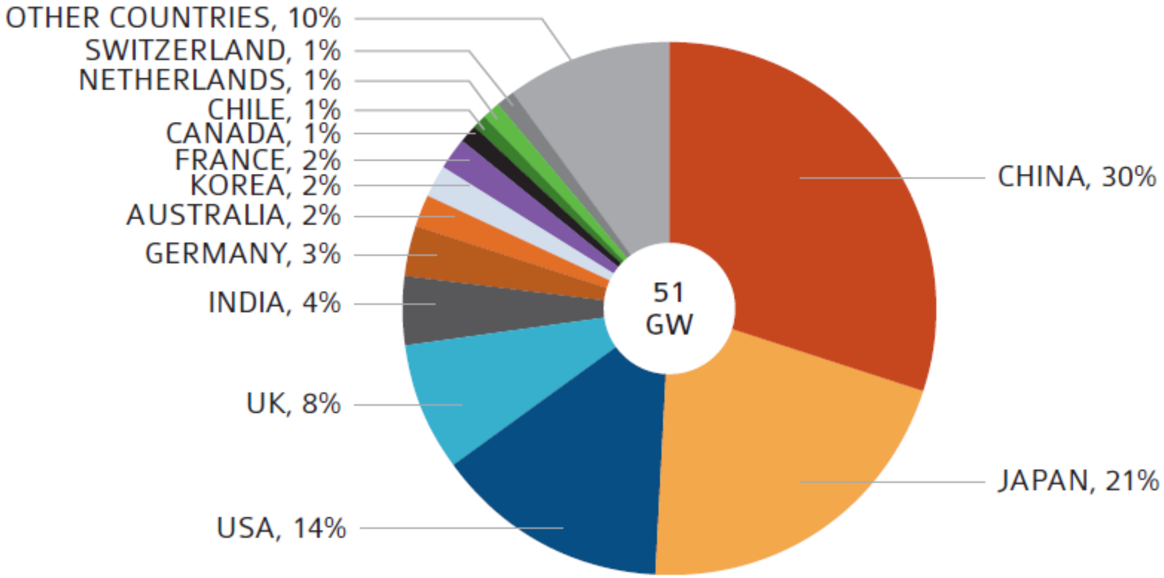
Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Global growth of PV capacity

Growth in solar PV systems



Cumulative PV capacity by end 2015



Global PV market in 2015

Operation and maintenance

Operation and maintenance

Figure 13: Examples of different types of soiling of PV arrays [83].

Operation and maintenance

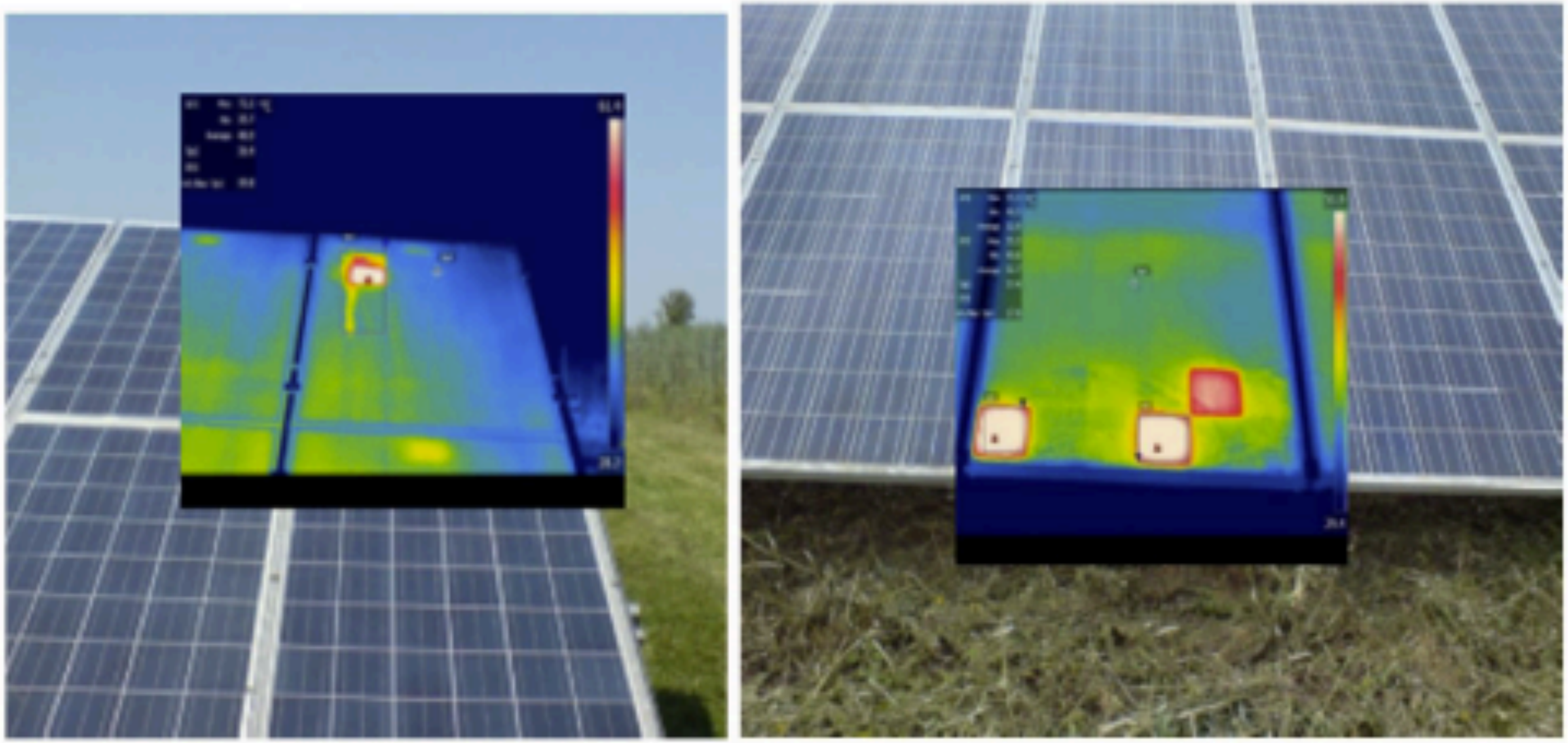


Figure 14: Impact of bird droppings and locally increased temperature (left), Impact of freshly cut green and unexpected hotspots (right) [Fraunhofer ISE].

What might be less known is the fact that O&M actions might also be a source of soiling if conducted in an erroneous way. Figure 14 right image shows a thermal image of a rack after fresh grass cuttings. It does make a difference if the lawnmower goes from left to right or vice versa if it throws out debris on one side only.

This heterogeneous soiling can also be seen in I-V curves from single modules. The difference to uniform soiling is the fact that heterogeneous soiling has a stronger influence on MPP rather than on I_{sc}, as can be seen in Figure 15.

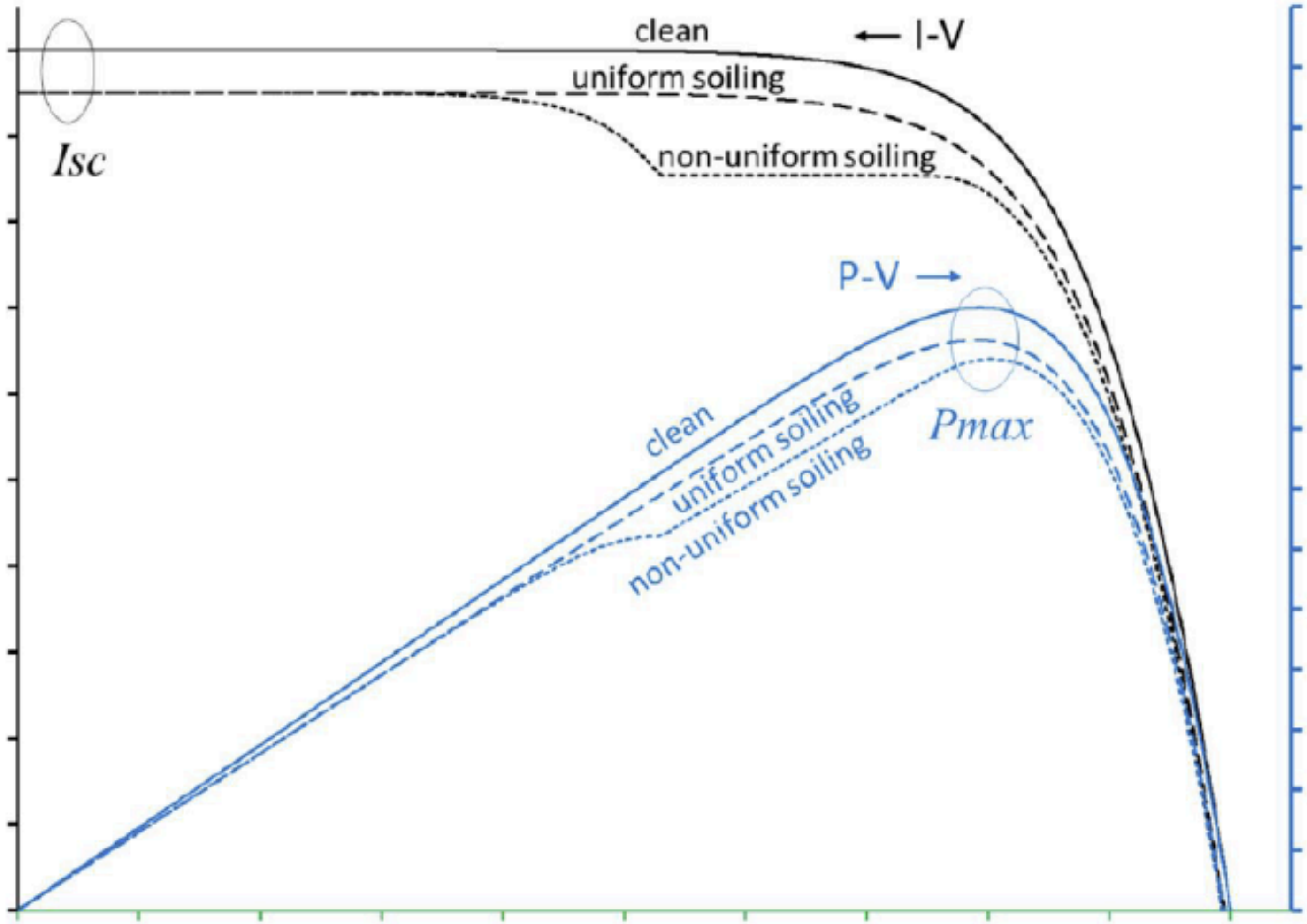


Figure 15: IV and P-V curves of clean, uniformly, and heterogeneously soiled PV modules [ATONOMETRICS soiling measurement system manual].

Operation and maintenance

Most animals living next to ground-mounted PV modules are farm animals such as sheep and small livestock (Figure 17). They can control vegetation in PV plants and usually do not climb on or damage the PV modules. The first row of modules might be exposed to them which could be pressed upon by their bodies when reaching for grass underneath the PV panels.

Figure 17: Farm animals in British solar farms [93].

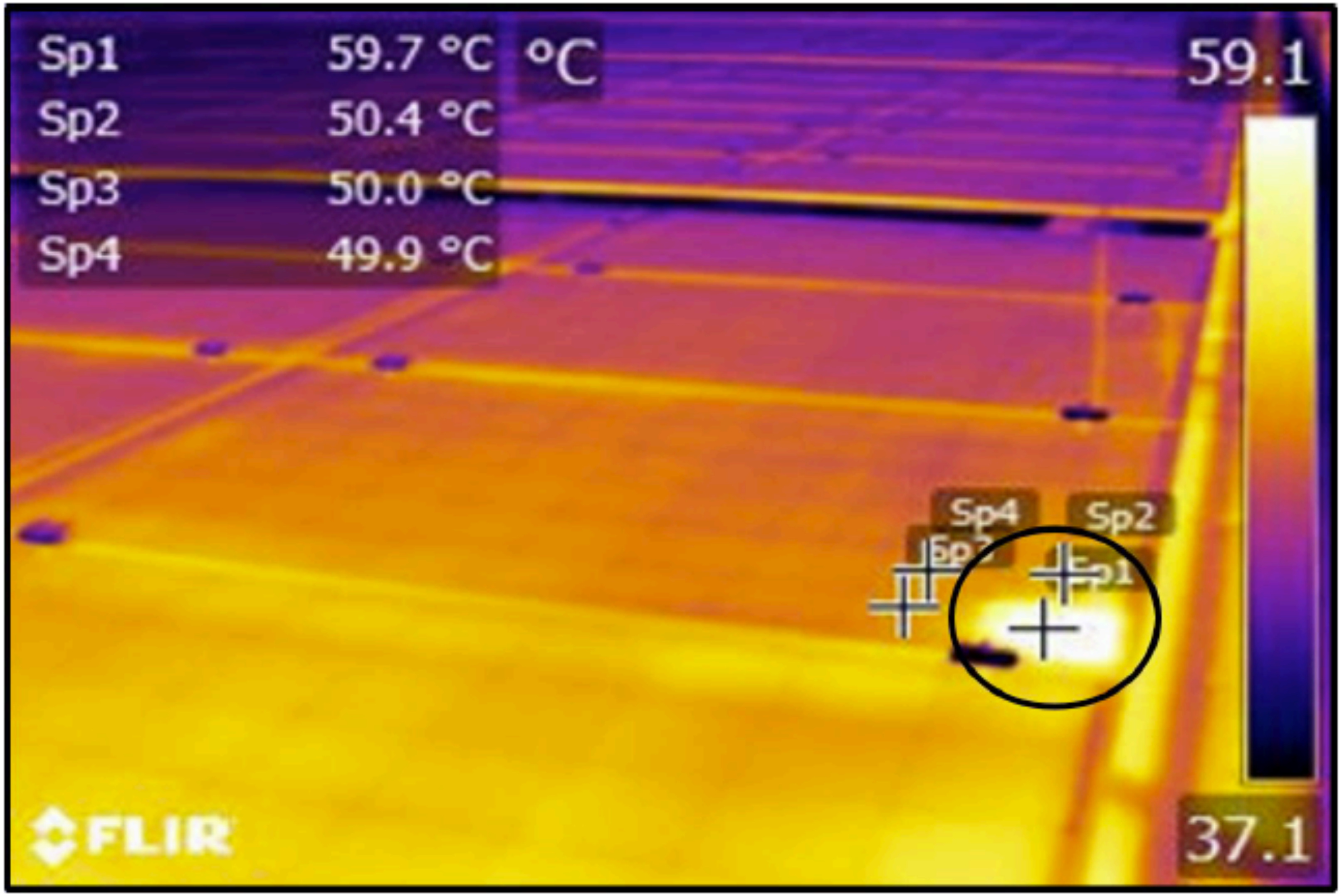


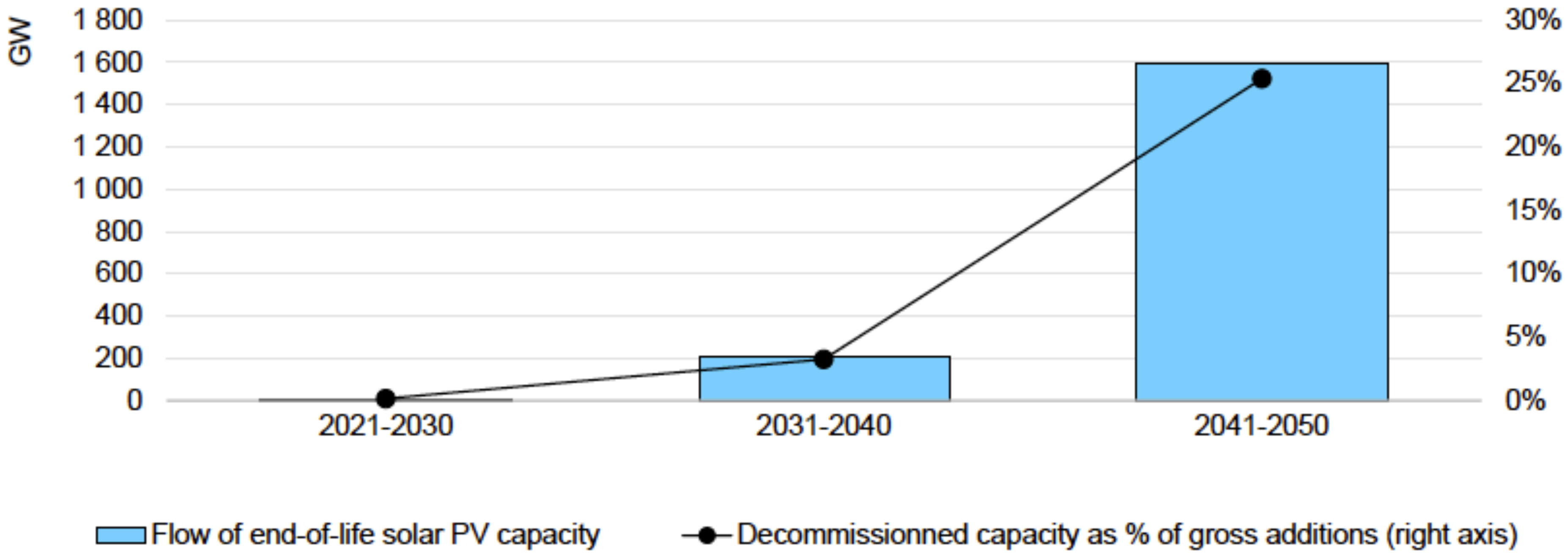
Figure 37: Modules with uneven stains on glass were seen to have developed hotspots with ΔT ~ 10°C.

A study of production losses associated with snow coverage in Konya, Turkey, [165] in January 2017 showed that daily losses due to snow cover could be almost 100%, and the monthly loss was 23%. Konya is located 38°N and 32°E at an elevation 1030 meters above sea level. Cleaned modules were compared with snow covered modules of the same type and situated at the same place, as shown in Figure 51.

Figure 51: The system in Konya, Turkey, where one string was cleaned from snow every day at 09:00 AM [165].

Decommissioning and recycling

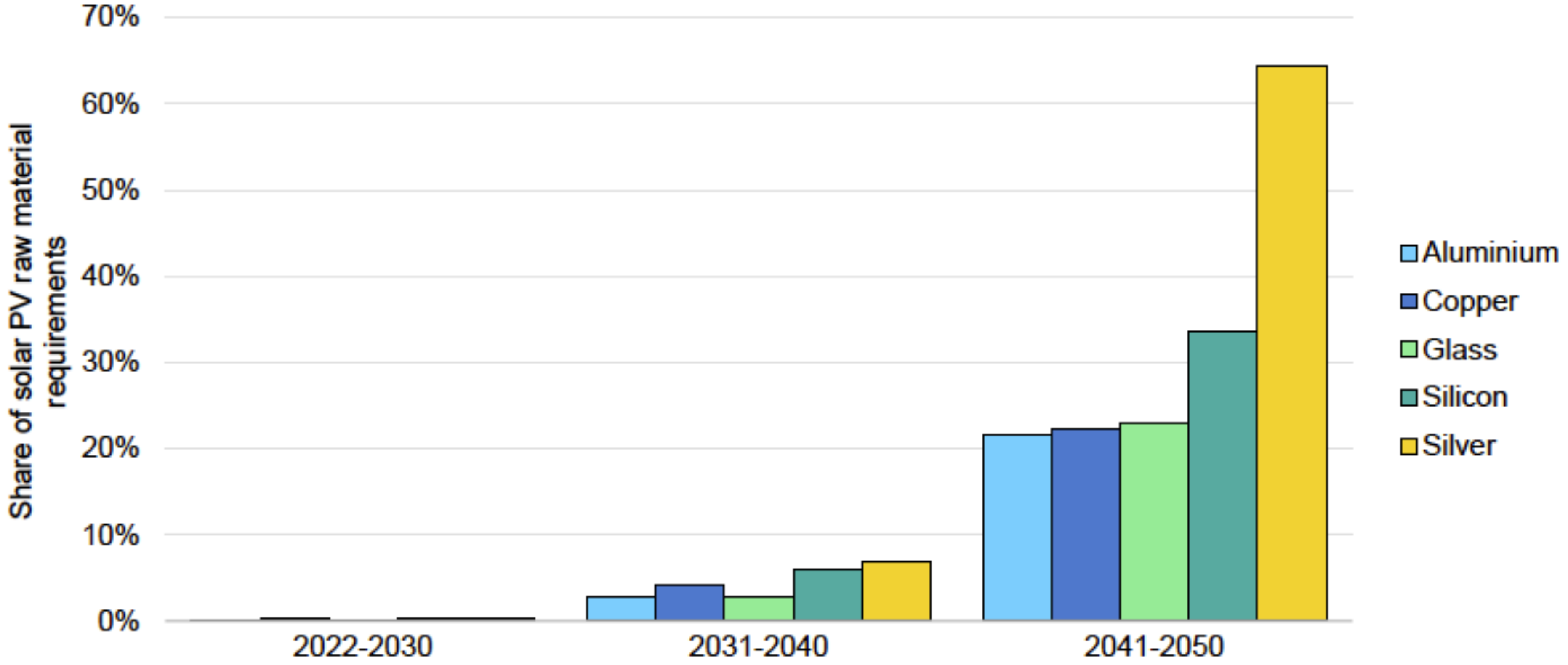
Expected flows of decommissioned solar PV capacity, 2020-2050



Notes: Values are based on historical capacity additions as well as additions modelled in IEA Net Zero by 2050 Scenario. Solar PV module lifetimes before decommissioning are assumed to follow a Weibull distribution pattern, with median lifetimes of 25 years for utility-scale installations and 30 years for distributed.

Source: Calculations based on IEA (2021f).

Potential contribution of module recycling to solar PV material demand under the Net Zero by 2050 Scenario for selected materials, 2022-2050



Note: Calculations take into account the historical evolution of material intensity in the different generations of solar PV modules put on the market since 1990 and assume further material intensity improvements of 10% over 2020-2050 for glass, 30% for silicon and 75% for silver. For the sake of simplicity, calculations assume a recovery rate of 85% for all materials. However, recovery rates above 90% for silver and up to 95% for silver and copper are considered achievable (Huang et al., 2017).

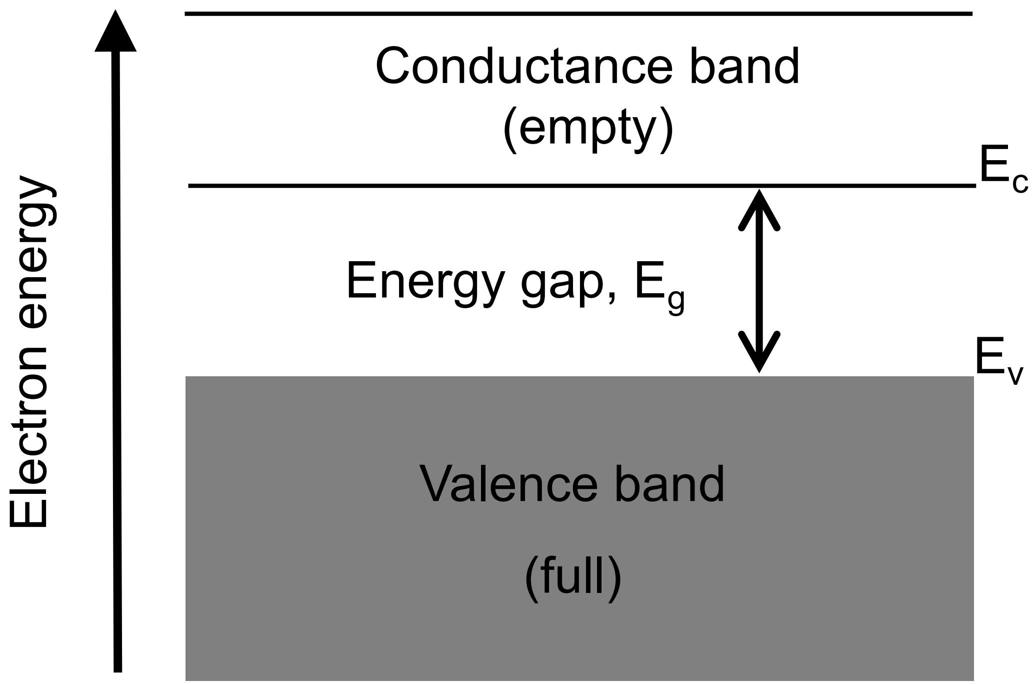
Sources: Calculations based on IEA (2021d; 2021f).

Fundamentals of photovoltaic

Electrical properties of semiconductors

The electrical properties of semiconductors can be explained using the band model

Band Model in Semiconductors



Quantum theory – electron energy must fall within strict bands

Conduction band – next highest band and separated from valence band by forbidden region called the **band gap**

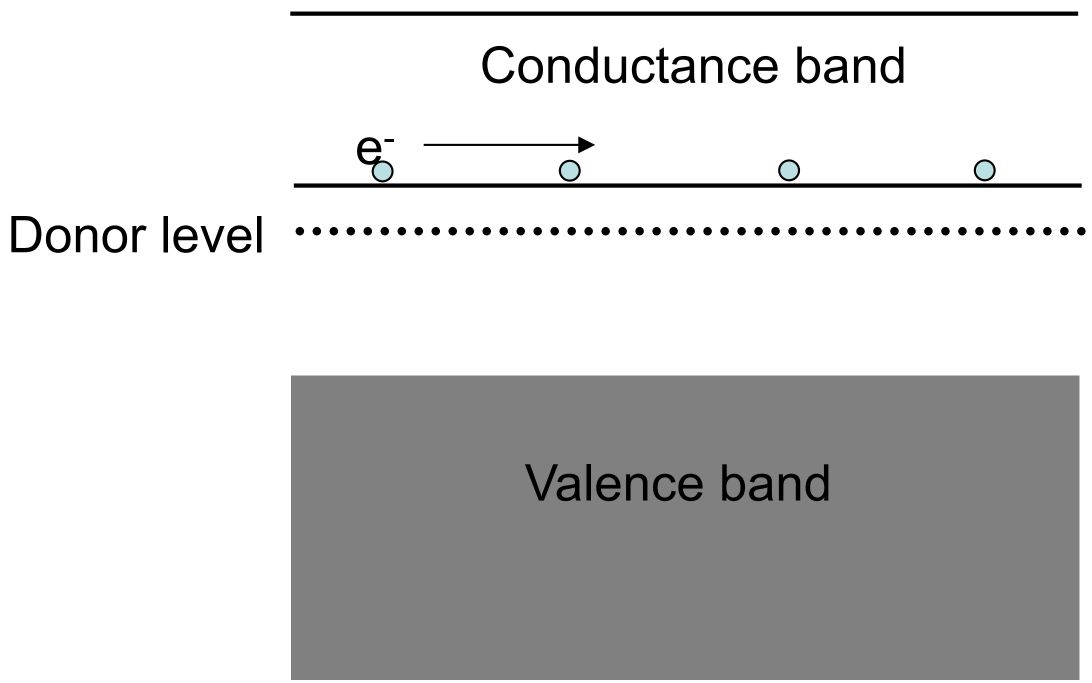
Valence band – electrons involved in forming bonds

Pure or Intrinsic semiconductor – e.g. Silicon

Electrons in the full valence band cannot move to conduct electricity and therefore a pure semiconductor is an insulator

Electrical Properties of Semiconductors

Impurities in Semiconductors



Charge carriers introduced into conduction band by addition of impurity – *doping*

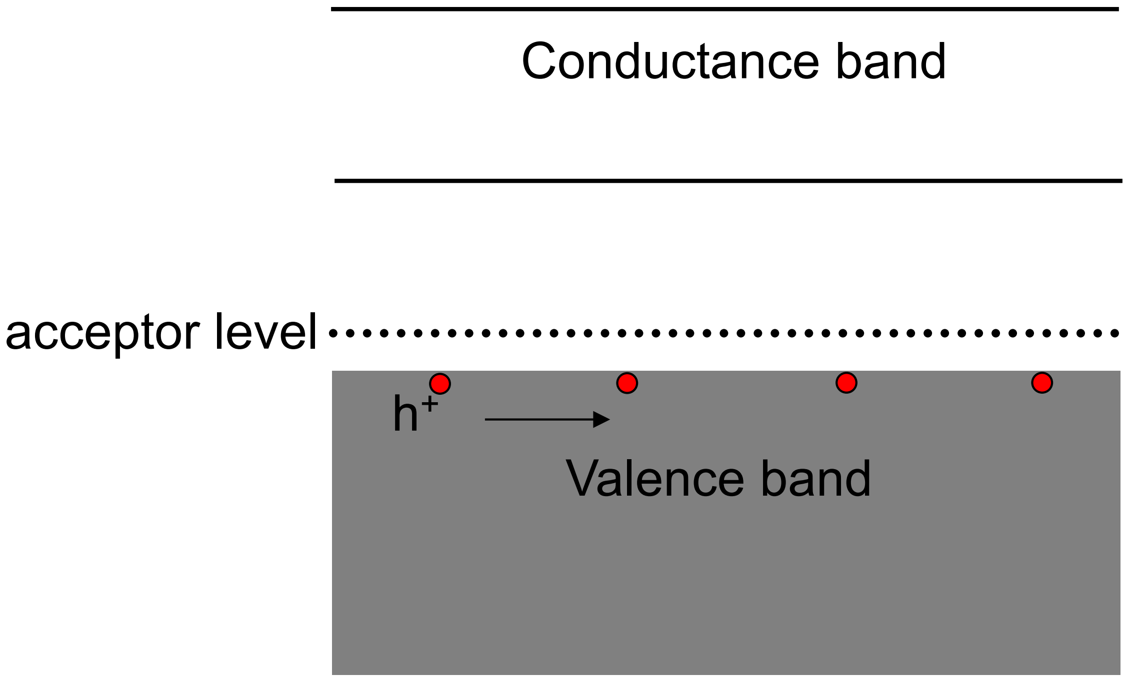
For example a Group V element like Phosphorus (P) with 5 outer electrons

Extra electron can be promoted to the conduction band and be free to move so P acts as *donor* impurity

n-type doped semiconductor – negative majority charge carriers

Electrical Properties of Semiconductors

Impurities in Semiconductors



Charge carriers introduced into valence band by addition of impurity – *doping*

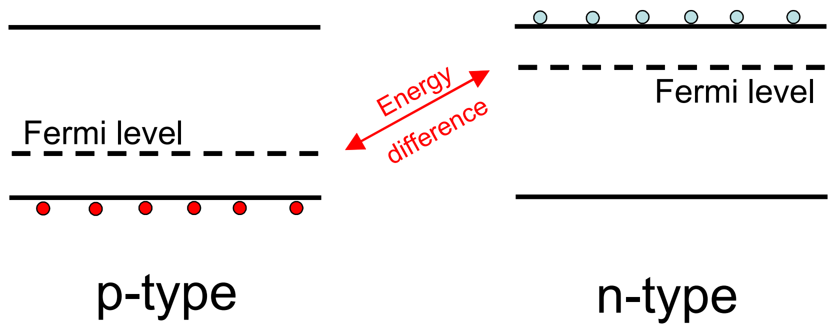
For example a Group III element like Boron (B) with 3 outer electrons

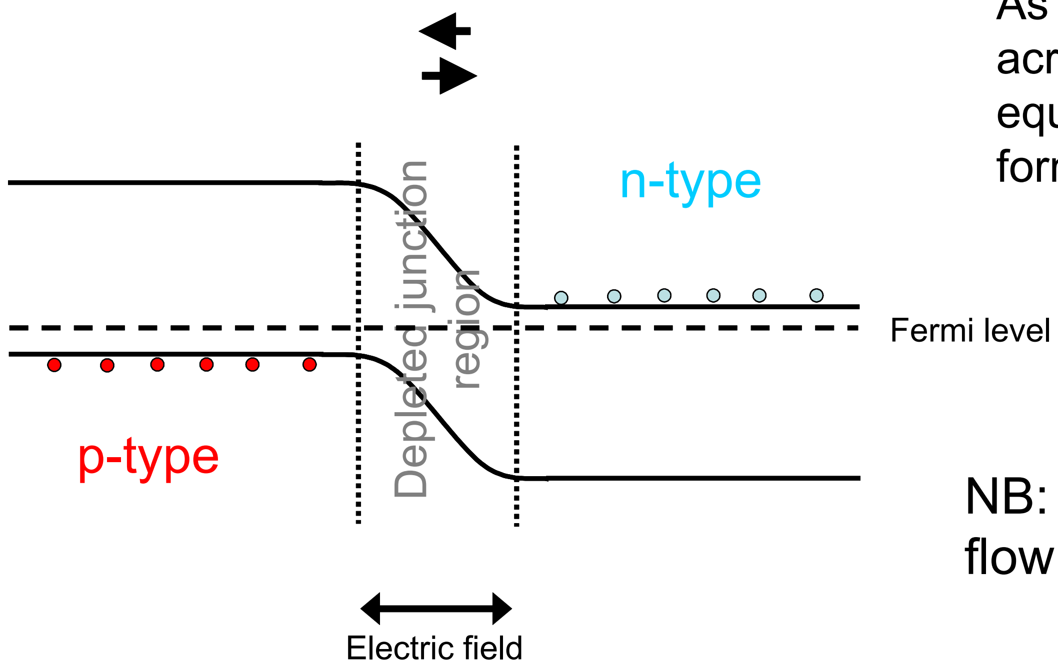
The boron atoms can accept electrons from the valence band effectively creating a positive hole and acts as an *acceptor* impurity

p-type doped semiconductor – positive charge carriers

P-N Junctions

When separate - Fermi levels within the *n* and *p*-type semiconductors are not equivalent





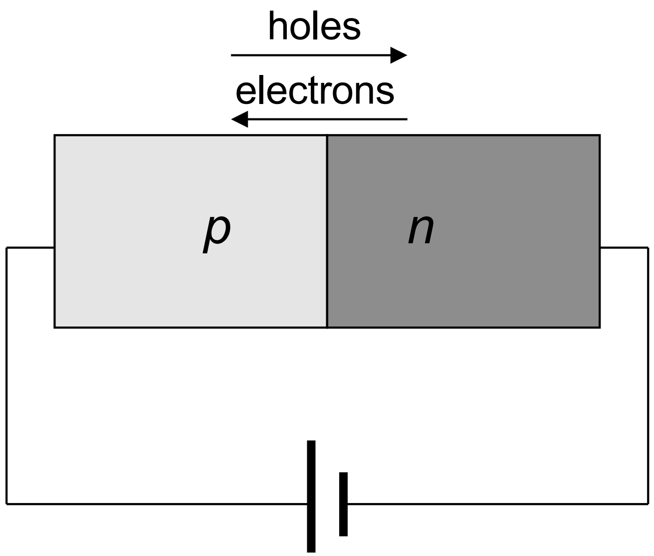
A *p-n* junction is formed at the interface between a *p*-type and an *n*-type materials

When joined, holes diffuse from the *p*-type material and electrons from the *n*-type material to form a charge carrier depleted region at the interface

As a result an electric field is established across the *depletion region* and at equilibrium a build-in potential of V_{bi} will be formed

NB: At equilibrium there is no net current flow across the junction

P-N Junctions – External voltage



On application of a voltage *V*, the built in potential reduces to $V_{bi} - V$ and the current increases exponentially with voltage, as in the *Ideal Diode Law*:

$$I = I_o[\exp\left(\frac{qV}{kT}\right) - 1] \qquad (1)$$

where I_o is the dark current, *k* is the Boltzmann constant, *T* is the absolute temperature and *q* is the electronic charge

NB

- I_o increases as *T* increases
- I_o decreases as material quality increases

The value of I_o is many times smaller than the current under forward bias and typically is of the order 10^{-14} A/m^2

For an actual diode, Eq. (1) becomes

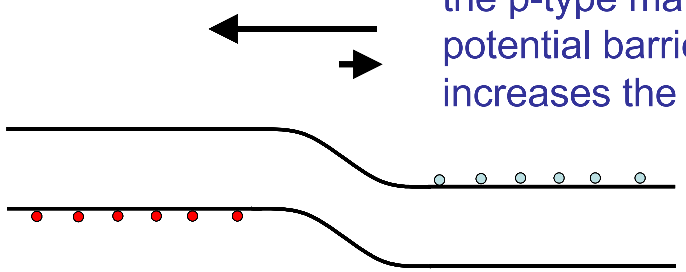
$$I = I_o[\exp\left(\frac{qV}{nkT}\right) - 1] \qquad (2)$$

where *n* is an ideality number, with value between 1 and 2. The value typically increases as current increases

P-N Junctions – Diode Behaviour

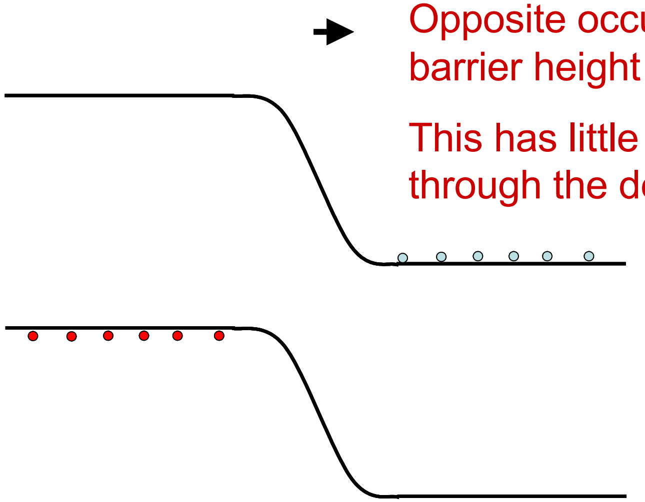
Illustration of typical current-voltage diode behaviour under external voltage

Forward bias



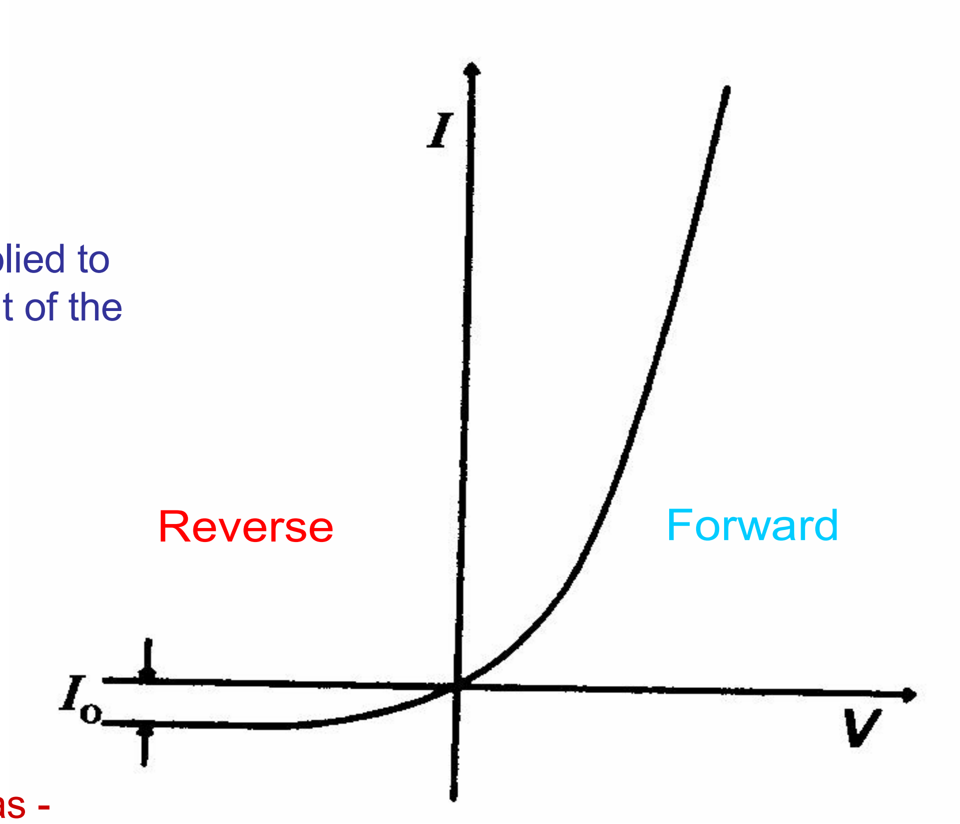
Forward bias (positive voltage applied to the p-type material) reduces height of the potential barrier. This dramatically increases the current

Reverse bias



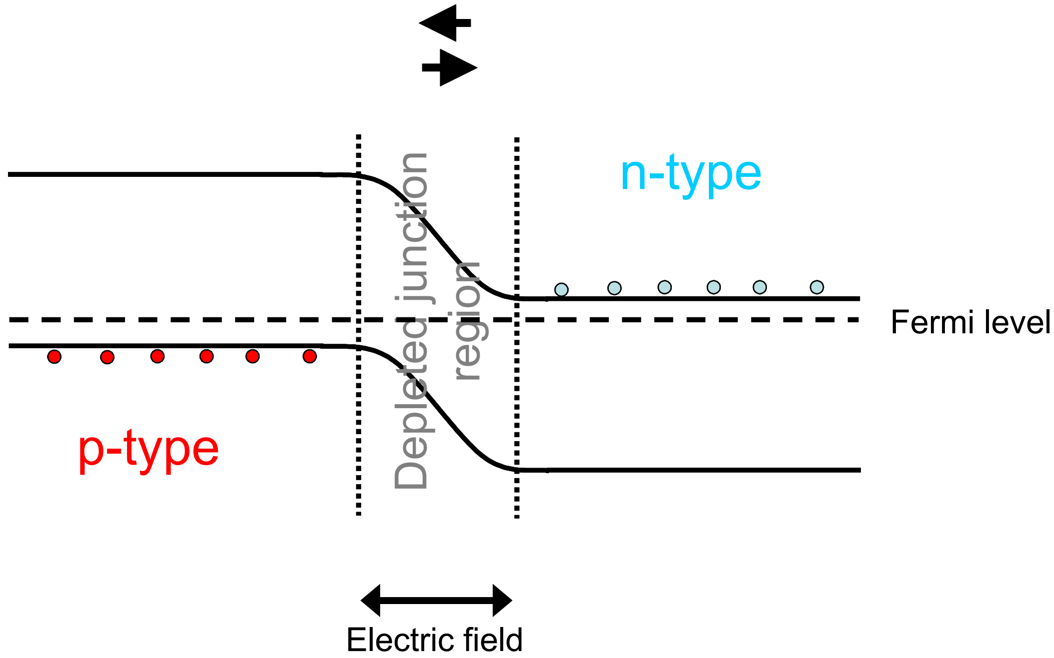
Opposite occurs under reverse bias - barrier height is increased

This has little effect on the current through the device

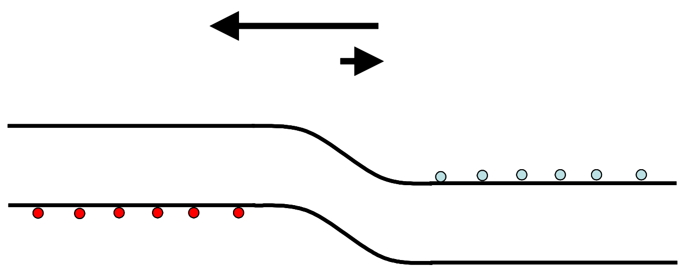


The Diode *I-V* characteristics (Source: Markvart, 2000)

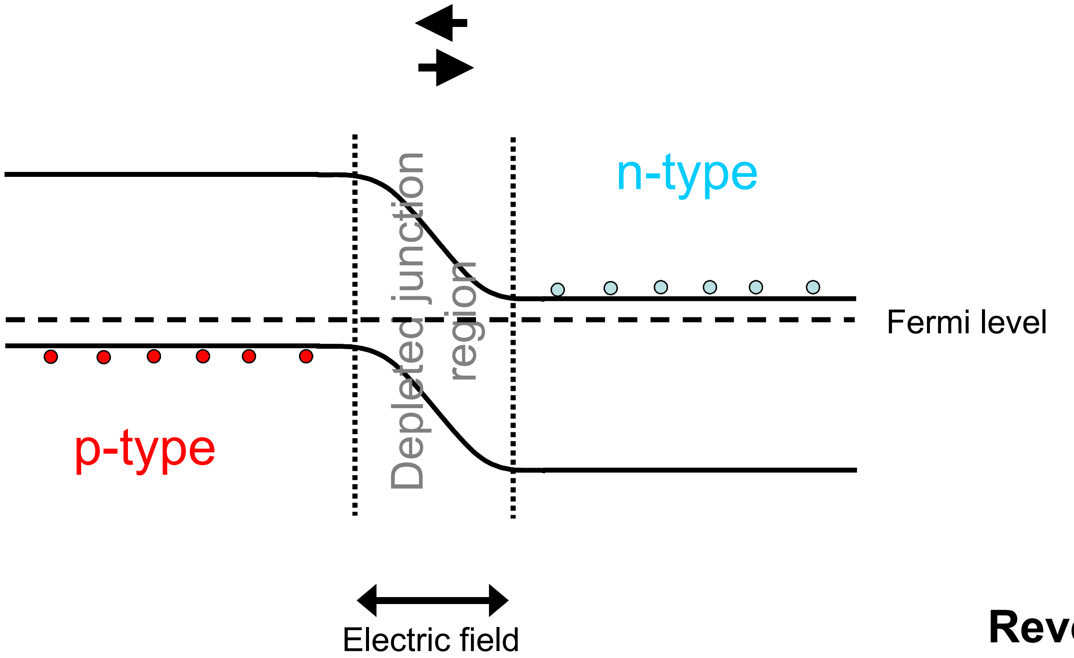
P-N Junctions – Diode Behaviour



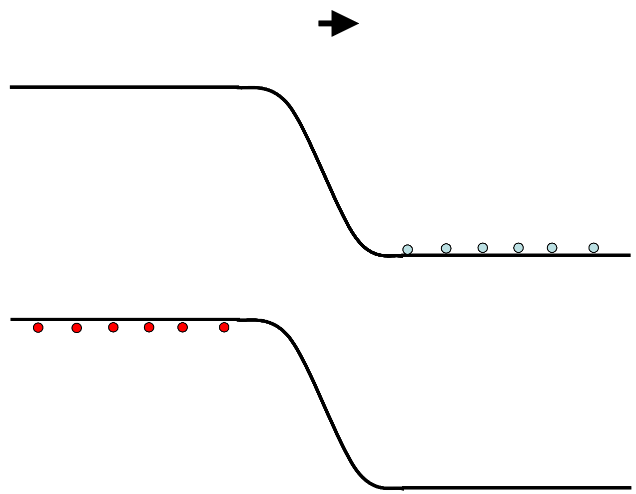
Forward bias



P-N Junctions – Diode Behaviour



Reverse bias



P-N Junctions – Diode Behaviour

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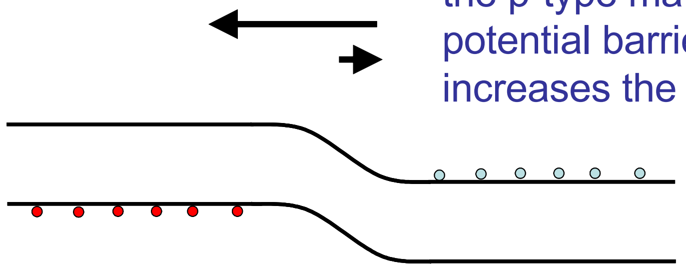

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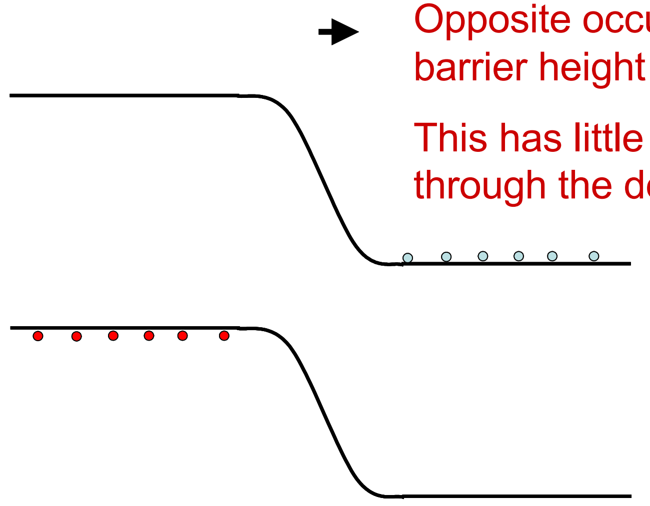

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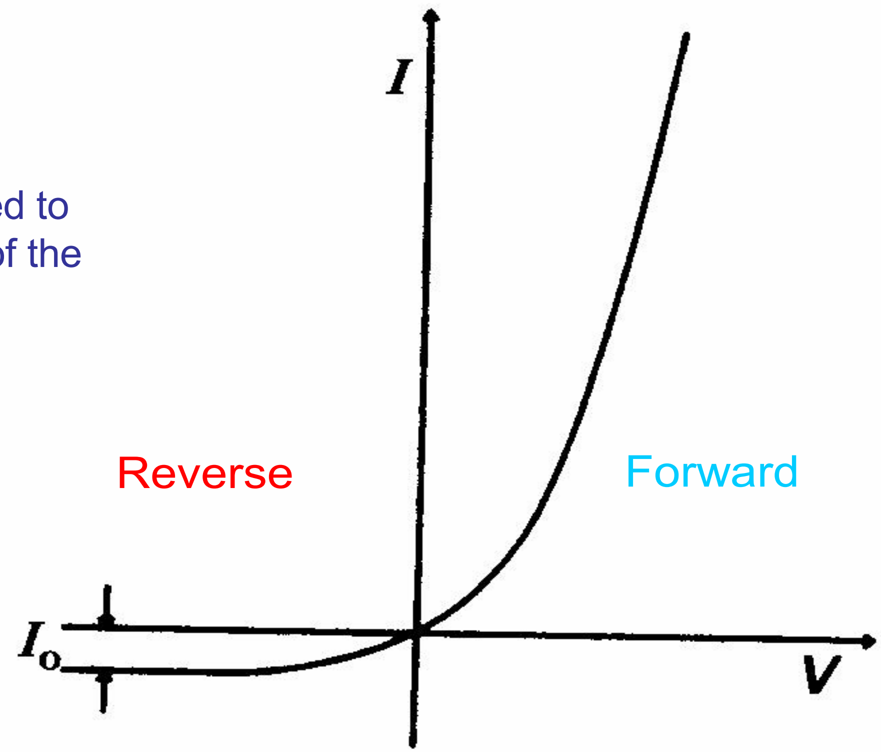


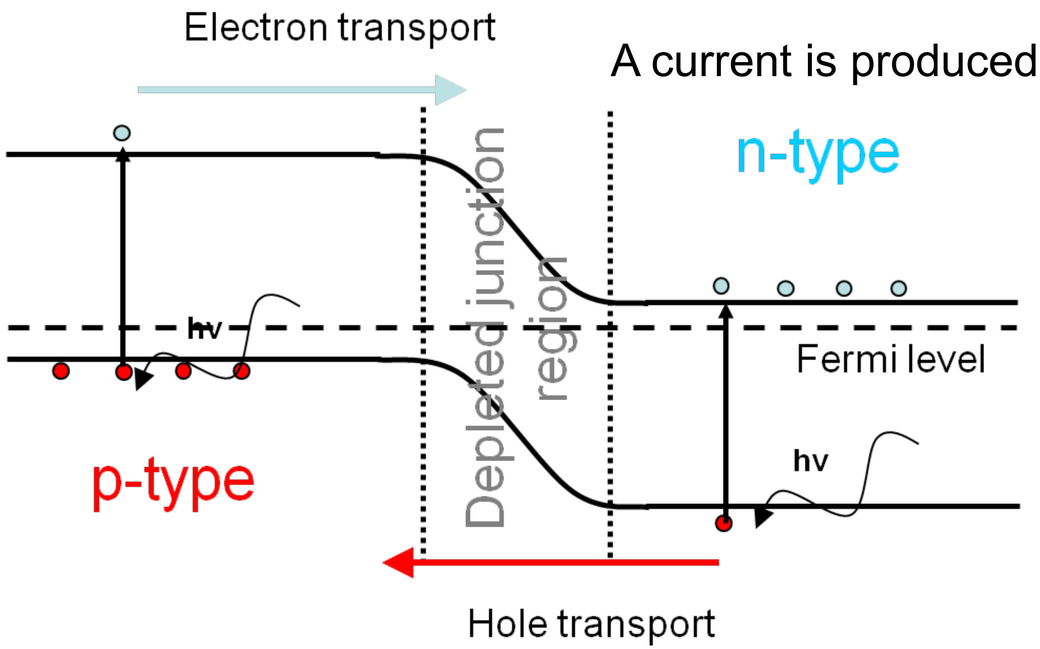
The Diode *I-V* characteristics (Source: Markvart, 2000)

Semiconductors – Effect of illumination

Light generates electron-hole pairs on both sides of the junction

The electric field at the junction sweeps electrons to the n-type side and the holes to the p-type side of the junction.

A current is produced.



This migration of minority charge carriers then produces an electric current across the device

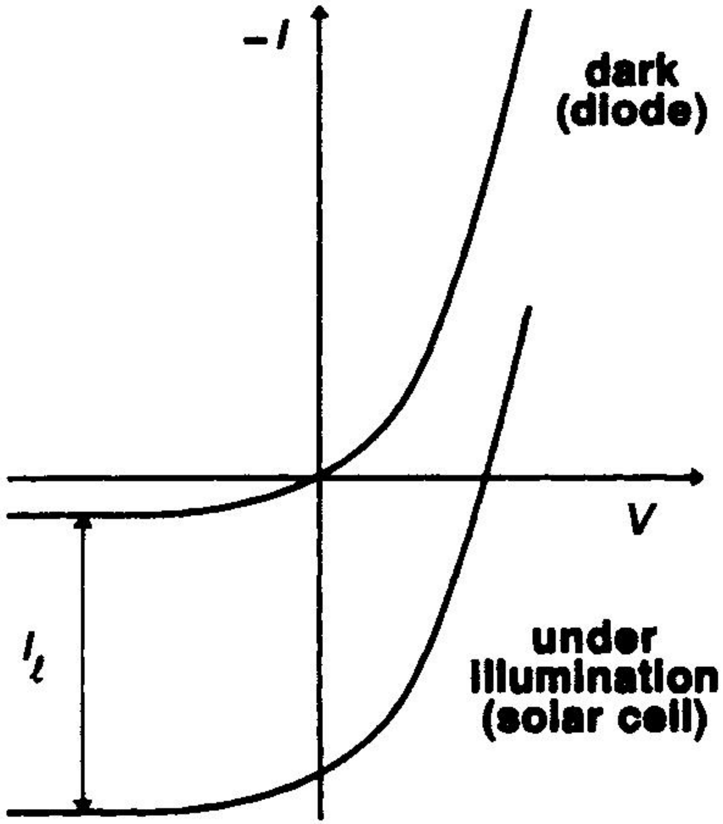
Not all electron-hole pairs are collected. The closer the point of generation to the junction the greater chance of collection

I-V curves under illumination

Illumination of the cell increases the current above the dark diode current.

The output current of the cell *I* is the difference between the light-generated current I_L and the dark diode current

$$I = I_l - I_o\left[\exp\left(\frac{qV}{nkT}\right) - 1\right] \qquad (3)$$



The *I-V* characteristics of a solar cell (Source: Markvart 2000)

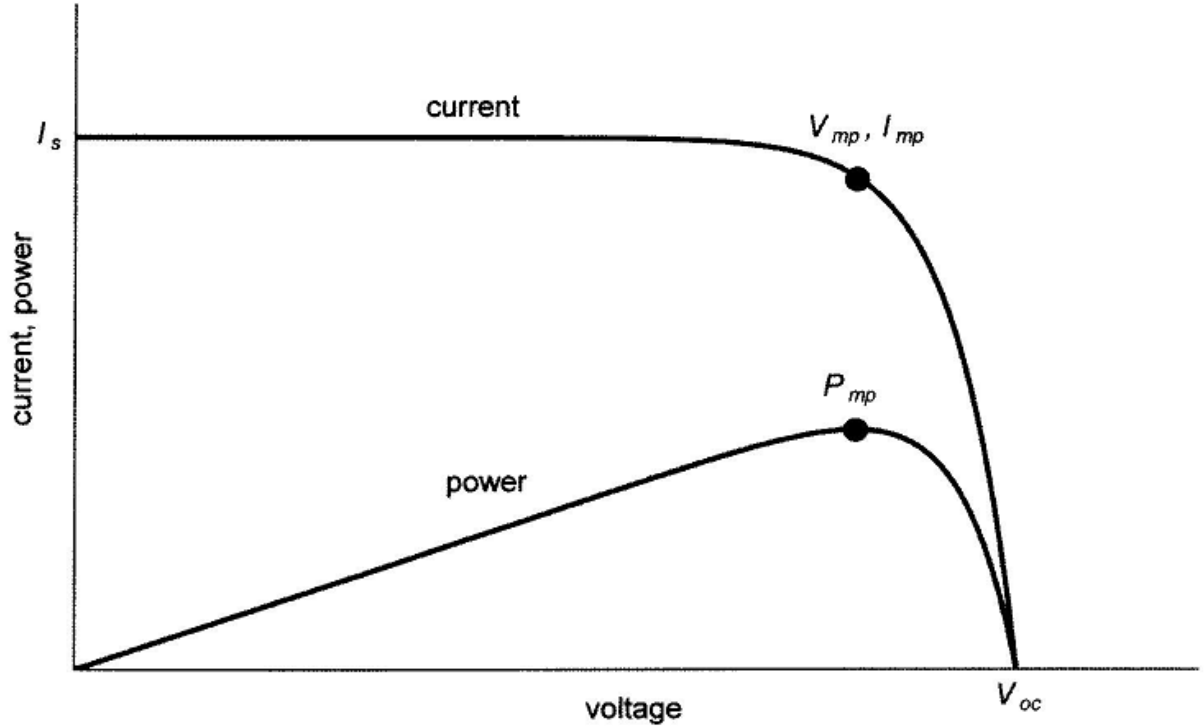
Solar Cells – Operating Parameters

For a given irradiance and operating temperature, the limiting parameters for solar cells are:

Short circuit current (I_{SC}) This is the maximum current when V = 0, hence $I_L = I_{SC}$

Open circuit voltage (V_{OC}) This is the maximum voltage when I = 0, hence $V = V_{OC}$ and

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{I_l}{I_o} + 1\right) \qquad (4)$$



The maximum power point (P_{mp}) is when product I x V is at a maximum ($I = I_{mp}$, $V = V_{mp}$)

Another important parameter to characterise junction quality and cell resistance is the *fill factor* (*FF*), where

$$FF = \frac{V_{mp} I_{mp}}{V_{OC} I_{SC}}$$

hence

$$P_{\max} = FF V_{oc} I_{sc} \qquad (5)$$

Solar cells – Effect of temperature

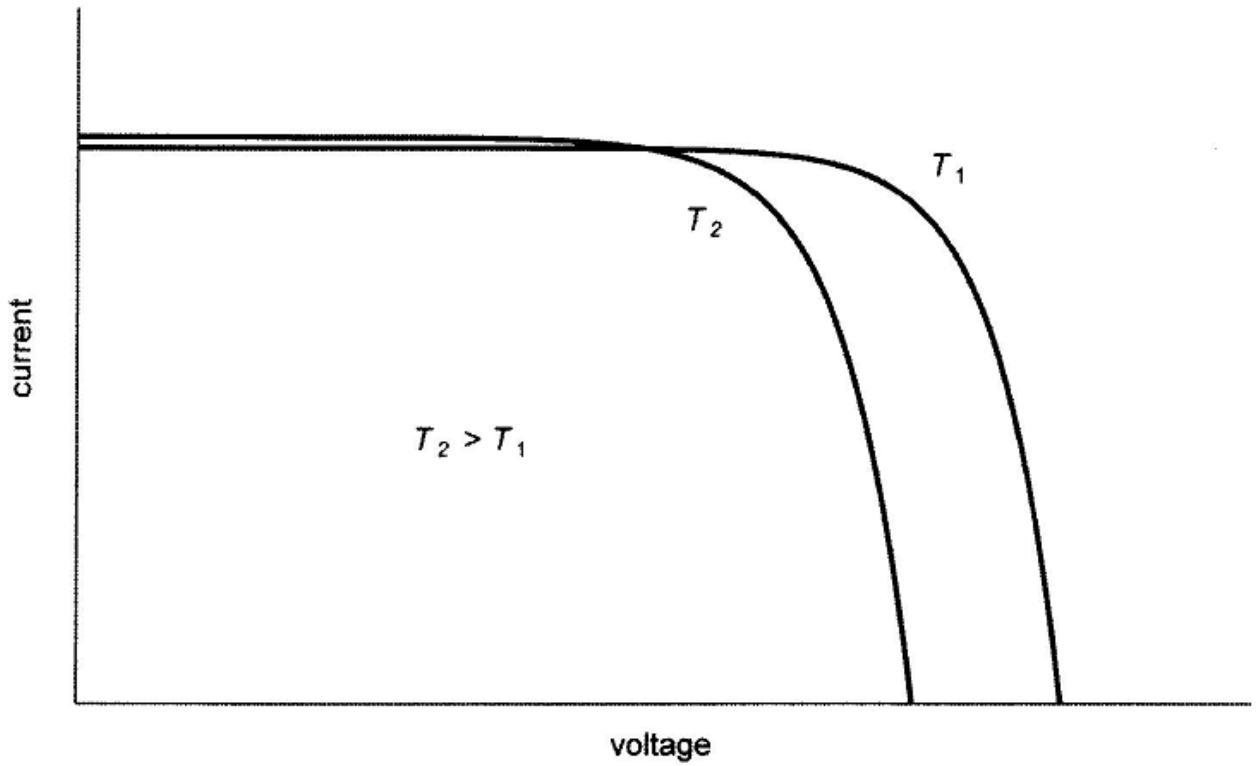
The cell operating temperature (*T*) has a small effect on the dark current (I_o) and short circuit current (I_{SC}); both increase with *T*.

However, increasing *T* for silicon cells reduces V_{OC}, *FF* and cell output

The maximum power point (P_{mp}) is inversely proportional to *T*, and described by

$$\frac{dP_{mp}}{dT} \approx -(0.0045 P_{mp})^{o}C^{-1}$$

The *Nominal Operating Cell Temperature* (NOCT) will be quoted for a solar cell



Effect of Temperature on solar cell I-V Behaviour

Ideal Solar Cell Performance

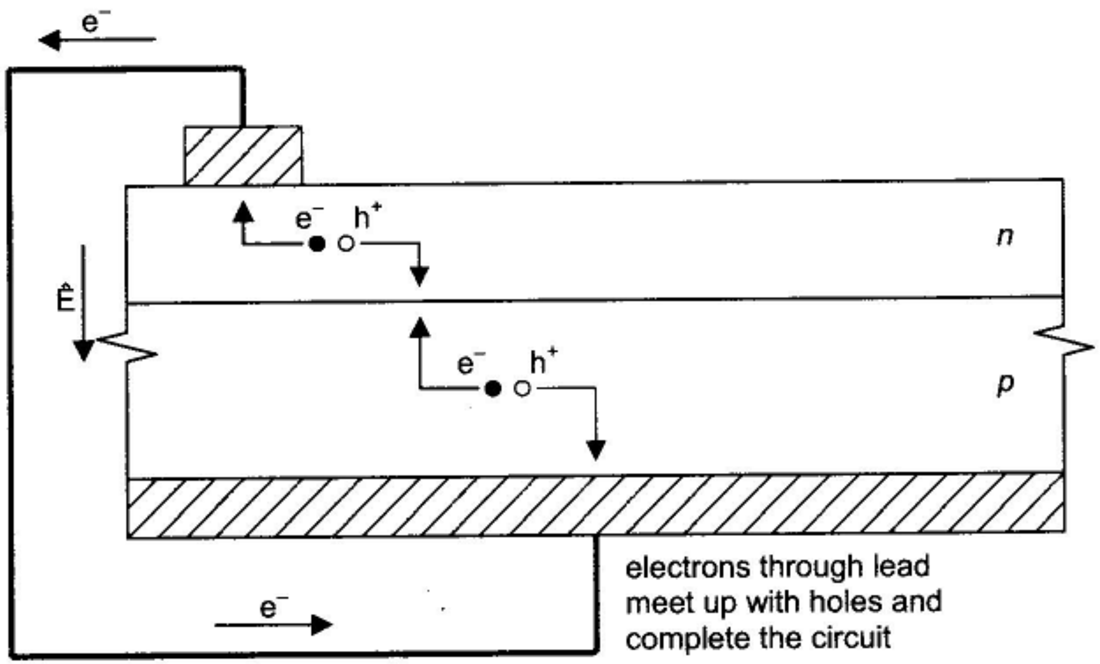
So far we have considered ideal solar cell behaviour

This assumes:

- Every incoming photon of light will produce an electron-hole pair
- Each electron-hole pair result in one electron flowing through the external circuit

NB: There are several reasons for reduced efficiency in solar cells

These can result in relatively low solar energy conversion efficiencies



Ideal short circuit flow and collection of electrons and holes within a solar cell

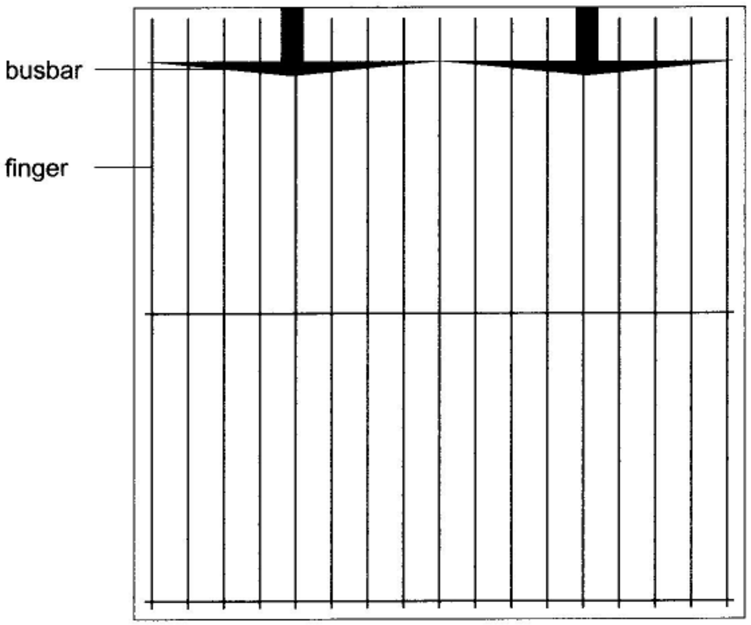
Optical Loss Mechanisms

Optical losses occur due to:

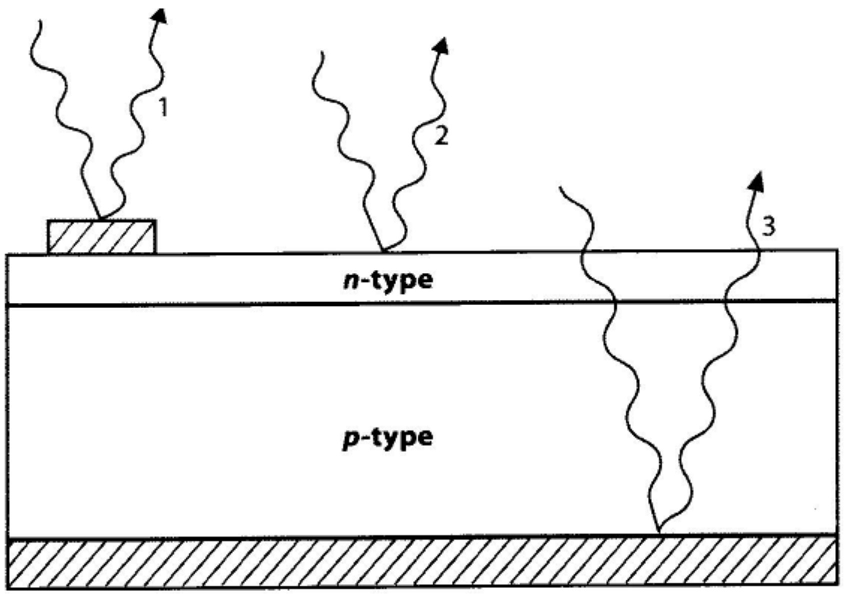
- Blocking of incoming radiation by the top contacts
  (minimise top contact area – but avoid significant increase in resistance)

- Surface reflection of incoming light
  (possible to use *anti-reflective coatings* (*ARC*) on top layer of cell or surface texturing)

- Reflection of light from rear contact



Top contact design in solar cells



Optical loss methods. (1) Blocking by top contact. (2) Surface reflection (3) Rear contact reflection

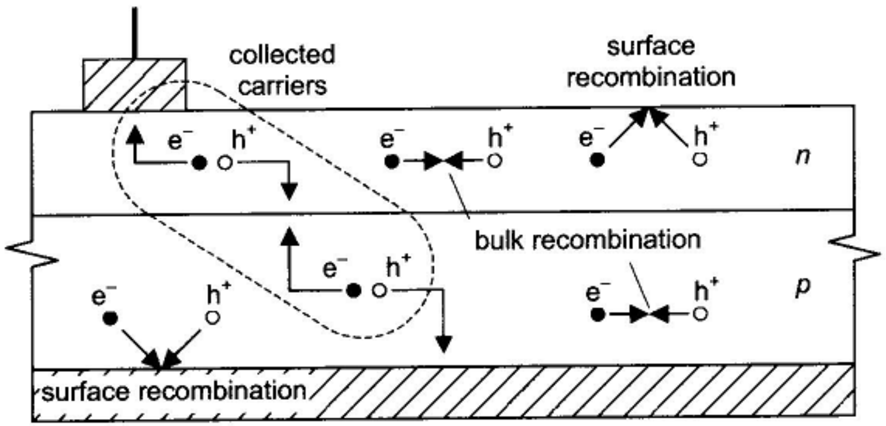
Recombination Loss Mechanisms

Efficiency can be reduced by the recombination of electron-hole pairs before they are collected and useful current produced. Recombination mechanisms include:

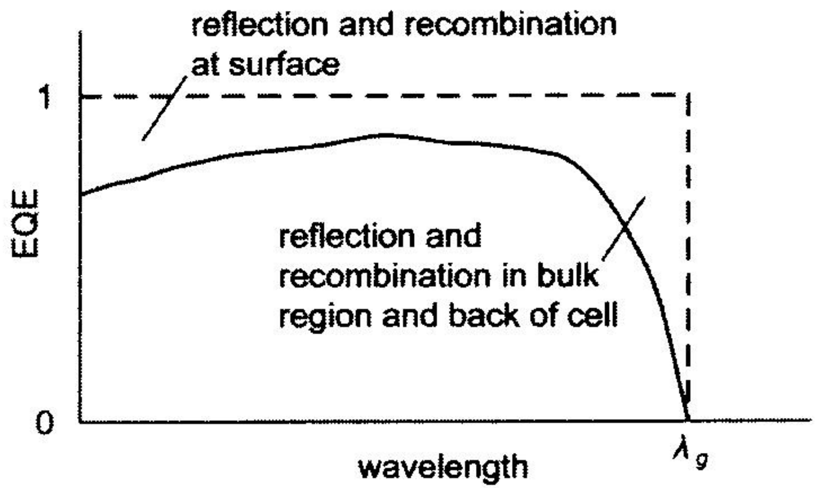
- ***Radiative recombination*** – relaxation of excited electrons by emission of light. This process is utilized in LEDs and semiconductor lasers but not desirable in solar cells

- ***Auger recombination*** – electron-hole recombination and release of energy. Particularly with highly doped materials

- ***Recombination at trap sites*** – occurs at impurities in the semiconductor material or at interface and surface sites which give rise to energy levels within the band gap



Types of recombination losses in solar cells

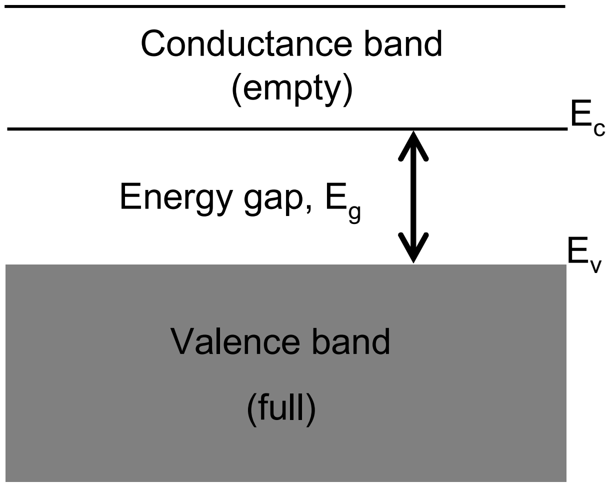


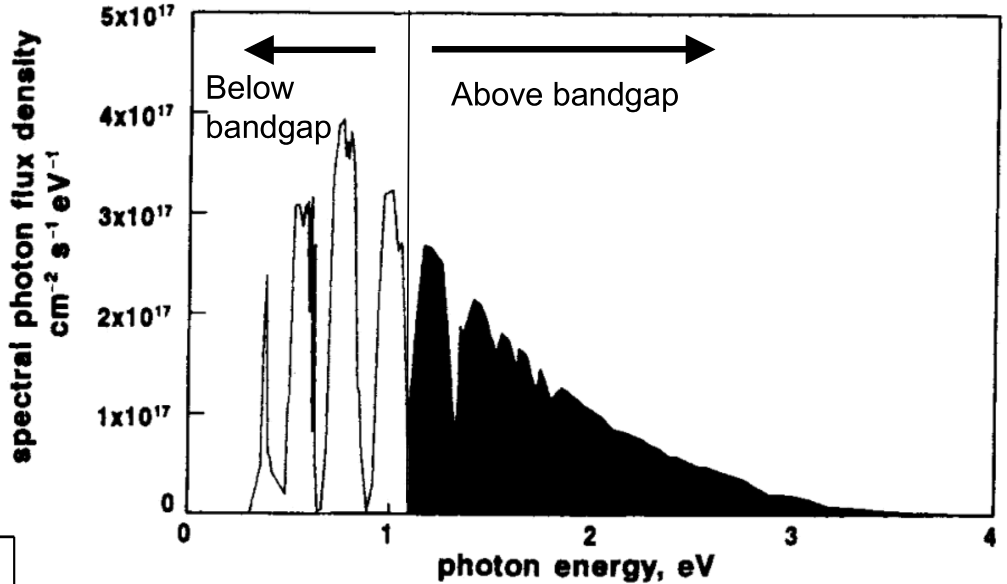
Effect of recombination losses on spectral response.

EQE, the *external quantum efficiency* - the ratio of number of electrons produced to number of incident photons

Below Band Gap Losses

Efficiency is limited to photons with energy in excess of the band gap. This limits the achievable efficiency to ~44%.





Effect of below band gap losses on spectral absorptivity

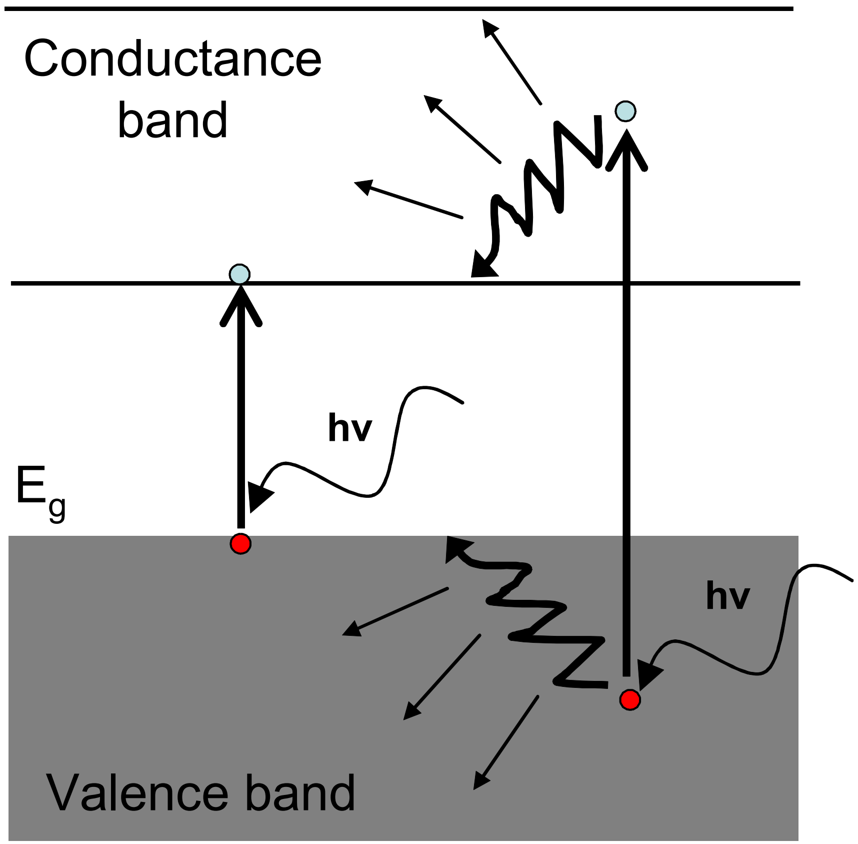
Material	Energy gap (eV)	Energy gap (J)
Crystalline Si	1.12	1.79×10^{-19}
Amorphous Si	~1.75	2.80×10^{-19}
$CuInSe_2$	1.05	1.68×10^{-19}
CdTe	1.45	2.32×10^{-19}
GaAs	1.42	2.28×10^{-19}

Optimal use of incoming radiation can only occur in materials with band gap in the range 1.0-1.6eV.

The band gaps of silicon and other commonly used semiconductors lie in this range.

Above Band Gap Losses

If photons with energy (E_{ph}) in excess of the band gap (E_g) are absorbed then this excess energy is quickly dissipated as heat



Heat generation by above band gap photon absorption

The spectral responsivity (*SR*), the amperes of current generated per watt of incident light, is calculated as follows:

$$SR = \frac{I_{SC}}{P_{in}(\lambda)} = \frac{q\lambda}{hc} EQE \qquad (6)$$

This is the maximum with photon energy close to that of the band gap. As the wavelength decreases, the cells cannot use all photon energy and progressively more is lost as heat.

Environmental Impact of Photovoltaics

Emissions from Photovoltaics

During operation no pollutants are produced – particularly no CO_2. However, during production some hazardous materials are used (e.g. Cd and As) but these are in small quantities. Energy is required in manufacture and this will have associated CO_2 emissions.

Solar panels only need to operate for 4-8 months to offset their manufacturing emissions.

Continuous innovation led by China has halved the emissions intensity of solar PV manufacturing since 2011.

Nonetheless, solar PV manufacturing represented only 0.15% of energy-related global CO2 emissions in 2021. As power systems across the world decarbonise, the carbon footprint of PV manufacturing should shrink accordingly. Transporting PV products accounts for only 3% of total PV emissions.

This payback period compares with the average solar panel lifetime of around 35-30 years.

Other Environmental Factors

PV systems have no moving parts and so cause no noise pollution

They are also generally not visually intrusive – being mounted on rooftops