Press Release



Photovoltaics Equipment

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International Technology Roadmap for Photovoltaics (ITRPV): Sixteenth Edition and Release of the New Digital Product

- Record year 2024: 703 GW PV module shipment
- TOPCon-Technology overcomes PERC dominance
- Release of new interactive digital ITRPV product

Frankfurt, 15 April 2025 – The 16th edition of the International Technology Roadmap for Photovoltaics (ITRPV) is now available for download (itrpv.vdma.org). Supported by data from 49 international expert institutions across the PV value chain, this new edition summarizes and discusses crucial parameters through numerous diagrams.

In 2024, the solar photovoltaic global market grew to a record 703 GW in shipments. By the end of 2024, the weighted average spot market price of crystalline silicon modules had dropped by around 33 percent compared to the end of 2023. The report tracks the price experience curve – average PV module sales price as a function of cumulative shipments – and it indicates a 25.6 percent learning rate from 1976 to 2024. This learning rate reflects the impact of technological advancements as well as severe market conditions on prices.

Silicon-based photovoltaics technology advancements

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President: Bertram Kawlath Executive Director: Thilo Brodtmann Crystalline silicon photovoltaics dominated about 98 percent of the market share in 2024, with the remainder being thin-film technology. Within the siliconbased photovoltaic market, monocrystalline Czochralski silicon (Cz-Si) wafers completely dominate the market share, with about 70 percent being n-type wafers surpassing p-type materials, according to GW-scale manufacturers that contributed to the report. This comes with the expansion of n-type TOPCon technology that dominates the market for the first time, overtaking p-type PERC. Silicon heterojunction (SHJ), and back contact cells back contact cells, TOPCon-based back contact (TBC) and heterojunction-based back contact (HBC) are expected to gain market share. Mass-produced tandem-silicon cells are anticipated to have a double-digit market share in 10 years based on the survey results. Large wafer formats M10 and G12 with their rectangular variations dominate. G12 (i.e., with wafer side length 210 mm) and G12(R) formats are expected to account for approximately 75 percent of the market by 2035. Formats larger than G12 are projected to reach nearly 10 percent, while the rectangular M10 format is anticipated to maintain a market share of around 15 percent. Accordingly, newly built cell production lines will be designed to accommodate these formats and are expected to be prepared for the integration of larger than G12 formats.

Bifacial solar cells are expected to have around 90 percent market share, a figure projected to increase over the next decade to 95 percent. The reduction of material consumption across various technology routes is a significant focus, including advancements in reducing polysilicon consumption through wafer thickness reduction, silver consumption reduction through fine line printing, and the use of copper-containing metallization. Equipment throughput values are anticipated to continue their increase in the coming decade. In n-type TOPCon cells, homogeneous emitters with Laser Enhanced Contact Optimization (LECO) dominate the market with around 60 percent share in 2024, projected to rise to nearly 87 percent by 2035. Selective emitters use declines with non-LECO variants phasing out by 2027. Edge passivation of separated solar cells by deposition processes also gain importance for half cells or smaller, dominating the market in a decade.

At the module level, copper interconnection is projected to continue dominating the market for cell-to-cell and string interconnection. For rooftop installations, modules larger than 2.0 m² are expected to gain a higher market share starting in 2025, while those between 1.8 and 2.0 m² will maintain the largest share. Smaller modules under 1.8 m² will see their market share decline to below 6 percent over the next three years. The module size trends for large-scale ground-mounted installations, like power plants, show a stronger shift toward larger modules compared to rooftop residential applications. Modules smaller

than 2.5 m² are expected to remain niche, while those between 2.5 and 3.0 m² will dominate the power plant market. Larger power plant modules, exceeding 3 m², are projected to capture about 25 percent of the market share in the next 10 years. The trend in module production fabs mirrors that of cell production, with factories exceeding 5 GW in annual capacity expected to dominate the future production landscape. However, smaller module fabs with capacities under 5 GW, and even under 1 GW, are anticipated to remain in operation for specialized applications and regional markets, even after 10 years. Smart fabrication topics show that batch tracking in manufacturing dominates with the increase of single piece tracking. Industry 4.0 is shaping cell production through four automation levels, ranging from fully connected fabs (Level 1) to autonomous decision-making fabs (Level 4), with higher levels incorporating all lower ones. While Level 1 dominated in 2024 with a 78 percent share, Levels 2 and 3 are expected to lead by 2035, and Level 4 will begin entering the market from 2029 with gradual adoption. For more detailed results, please refer to the full report.

New Interactive Digital ITRPV Product

The 16th edition ITRPV questionnaire is surveyed on a digital interactive platform that automates the analysis process of data contributions. Apart from the report creation process optimization, the aim of the new digital product is to enhance the user experience and offer exclusive interactive features to contributors and VDMA member companies. The regular yearly uploaded document will be offered for download to the public like every year.

ITRPV

The International Technology Roadmap for Photovoltaics (ITRPV) is updated regularly by the VDMA Photovoltaics Equipment sector group with contributions from leading international crystalline silicon producers, wafer suppliers, cell manufacturers, module manufacturers, PV equipment manufacturers, material manufacturers as well as PV research institutes and consultants. The aim of the ITRPV is to provide information on expected technology trends in the crystalline silicon (c-Si) based photovoltaics industry and to initiate discussions on required technological improvements and standards. For additional information, please visit the website (itrpv.vdma.org).

The smarter E Europe / Intersolar 2025 Side Events

The VDMA Photovoltaics Equipment sector group is organizing the two side events. First one on the 6th of May, titled: "European/German PV Production Technologies: Equipment and Technology Transfer for Global Manufacturing" Second event on the 8th of May: "Advances in Solar PV Production Technologies – Key Findings from ITRPV 2025" is dedicated to the results of this 16th edition and the showcasing of the new digital ITRPV product. As places are limited, events are only with official invitations and registration by contacting the VDMA Photovoltaics Equipment team.

Do you have any questions? Dr. Puzant Baliozian, Sector Group Leader VDMA Photovoltaics Equipment looks forward to answer them: 069 6603 1979, <u>puzant.baliozian@vdma.org.</u>

The VDMA represents 3600 German and European mechanical and plant engineering companies. The industry stands for innovation, export orientation and SMEs. The companies employ around 3 million people in the EU-27, more than 1.2 million of them in Germany alone. This makes mechanical and plant engineering the largest employer among the capital goods industries, both in the EU-27 and in Germany. In the European Union, it represents a turnover volume of an estimated 870 billion euros. Around 80 percent of the machinery sold in the EU comes from a manufacturing plant in the domestic market.