WHITE PAPER

Challenges & Trends for Emerging Solar Cell Technologies

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The solar industry is no stranger to complex political, regulatory, and supply-chain hurdles. From material shortages to tariffs, both real and threatened – these challenges are often used as foundations for arguments against its validity.

Photovoltaic effects were first discovered by French physicist Edmond Becquerel in the 1800s. By 1954 researchers at Bell Laboratories demonstrated the first practical silicon solar cell[1]. Yet these early solar cells were inefficient. Both time and technology prevailed.

Since 2020 solar power has risen to become the cheapest energy form on the planet. Of the wind, solar, and other renewables, nearly two-thirds – 62% – were cheaper than the cheapest new fossil fuel, according to the International Renewable Energy Agency (IRENA)[2].

Scientific and commercial progress remains buoyant, with an increasing number of solar farms progressing despite the ever-changing challenges they face. Innovative breakthroughs in key materials like glass, silicon, and polymers are driving the technology forward. Scientists rely on analytical solutions which can test for the desired properties needed for solar components including cells, wafers, and interconnections.

The global polymer photovoltaic solar technology (PV), or PV electricity market is expected to grow from 76.6 billion USD in 2020 to 113.1 billion by 2025, at a compound annual growth rate (CAGR) of 8.1%[3].

To put it in perspective, in 2003, 750 megawatts was the worldwide production capacity, while in 2019, around 130 gigawatts of PV modules were produced. Therefore, in just 17 years the production has been increased by more than 150 times and we are coming close to the Terawatt age. Indeed, the latest data shows that in 2021 the world reached 175 gigawatts - proof of that continuing trend. In two or three years we'll have more than one terabyte of PVs installed worldwide. China leads the market for installations, followed by North American which in 2021 overtook Europe (now the 3rd largest contributor) followed by India, and Japan. Combined, these accounted for 88% of the total installations in the world[4] in 2020. Data for 2021 shows that the top 10 counties (Australia, China, India, Japan, Korea, Germany, Spain, France, Brazil and the USA) represented around 74% of the global annual PV market, a slight decrease compared to 2020.[5]

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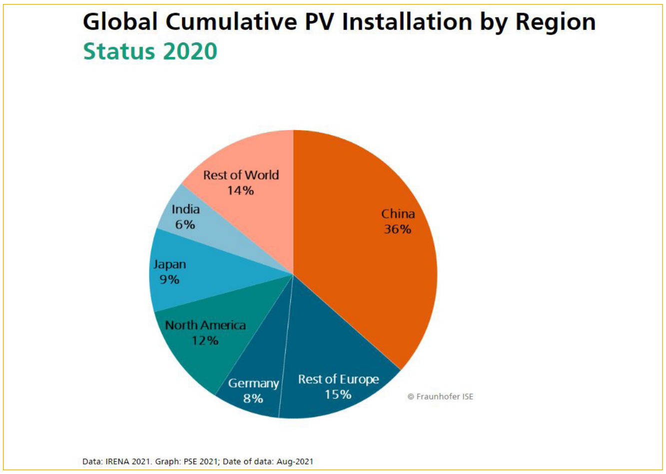
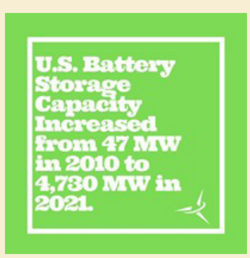


Figure 1: Top Countries Driving PV Market Growth. Data Source IRENA 2021 via Fraunhofer ISE.

As the solar industry continues to mature, the industry works to right itself, addressing and rectifying issues that slowed down growth in the past. For example, subsidies for installment were once needed, especially for regions with less sun. But these subsidies are not needed anymore, as they are now able to produce a good amount of solar energy. The average price of PV modules fell by 20% — doubling the production volume. The bigger bottleneck is now energy storage. When we produce more energy than we need — where can we store it or how can we share/sell that surplus?

BATTERIES: STORING THE SUN'S POWER



Credit: KeenMinds

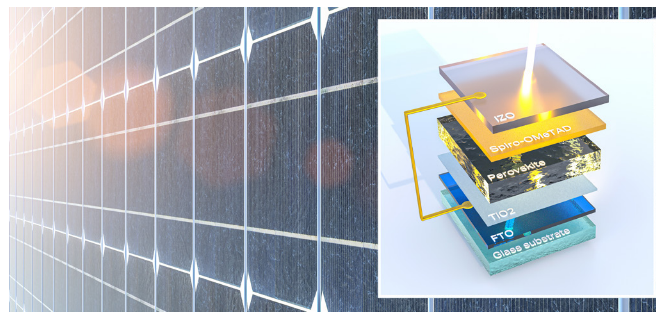
Storage allows the flexible use of energy anytime, not just when it was generated. Energy Storage occurs through batteries and fuel cells. R&D continues to explore a myriad of material and chemical combinations for different applications. The energy-storage mechanism we will ultimately adopt for our factories and our homes will be different to that which we install in our phones or cars. Read more about battery analysis here.

The Greatest Challenge for Emerging Solar Cell Technologies: Outliving Silicon Modules

Crystalline silicon is the dominant semiconducting material used in PV for the production of solar cells. It makes up 95% of the PV market. There are silicon modules in the field that are over 40 years old and still producing 80% of their initial power.

A small amount of the market utilizes thin film technology, which is actually Cadmium Tellurite (CdTe). CIGS - Copper, Indium Gallium Selenide Solar cells are also available, but they are small compared to crystalline silicon.

Emerging technologies include organic PV, dye sensitized, or Perovskite solar cells. So far organic and dye sensitized cells have proven to be inefficient and can cause serious issues. They have been under extensive research due to their simple preparation methodology, low toxicity, and ease of production. However, issues remain because of their comparatively low efficiency and stability when compared to silicon solar cells.



Silicon Wafer Sizes Are Changing Outputs

Important innovations are also happening because of the changing sizes of silicon wafers used to make solar cells. The wafers are getting bigger, and with that the solar cell size is also increasing. This profoundly impacts which kind of solar cell technology is being used. Producers can cut these wavers into half cells, quarter cells, or in other shares and connect the cells. This technique allows them to reduce the serial resistance and increase the active area. By doing that, they actually get models with higher power output. As shown in Figure 2, wafer sizes are projected to change exponentially in the next 10 years.

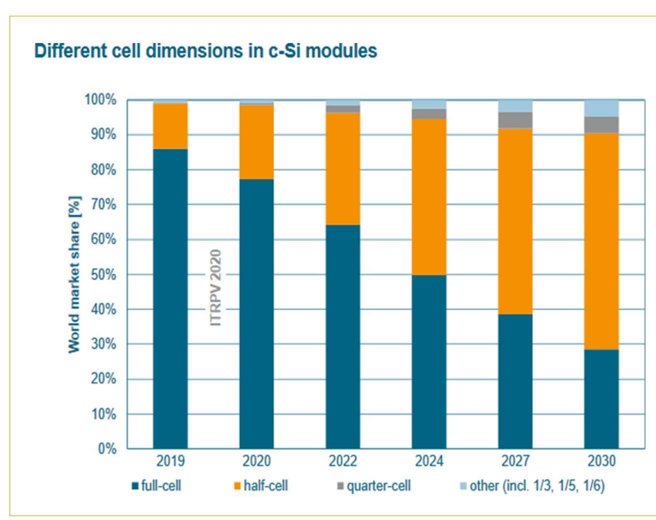


Figure 2: Different Cell Dimensions

Source: International Technology Roadmap for Photovoltaic (ITRPV), published by VDMA

The market is also seeing a seismic shift in cell technologies that will change solar panel production.

Higher energy conversion efficiency can be achieved by adding a dielectric passivation layer on the rear of the cell. These cells are known as PERC (Passivated Emitter and Rear Cell). Heterojunction technology (HJT) is a method on the rise as well. HJT combines two different technologies into one cell: a crystalline silicon cell sandwiched between two layers of amorphous "thin-film" silicon. Compared with using any technology alone, these technologies can be used together to harvest more energy. It is currently the solar industry's most effective process for increasing efficiency and power output to the highest levels. It is predicted that PERC and HJT will become dominant cell technologies in the future and half-cell silicon wafers will gain more market share[6].

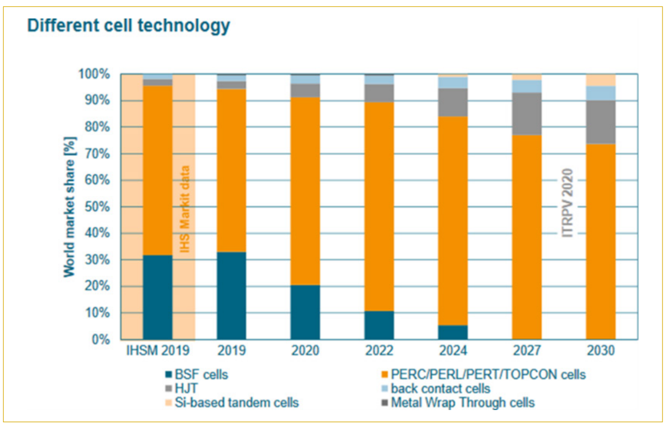


Figure 3: A breakdown of cell technologies

Next to the advances in cell technology, the interconnection of the cells is changing rapidly. There is a strong focus on multi wires, where 18-25 very thin wires are used. These wires put less stress on the solar cells, reducing the danger of solar cell breakage, using lower solar temperatures, and creating a larger active area.

Novel Trends in Solar Technology

A fascinating new trend in solar tech is shingling. This simple principle is based on what you see on the roof of most homes. Producers just overlap the solar cells and don't use any wires or ribbons for connectivity.

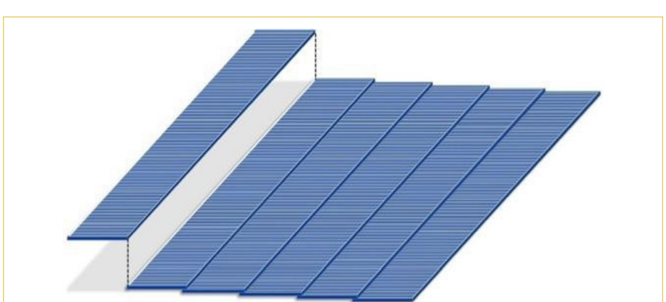


Figure 4: Solar Shingling Utilizes Overlapping Solar Cells for Connectivity

Structured foils are also an emerging technology. In this methodology, all contacts, the anode, and the cathode of the solar cell are on the back like a printed circuit board.

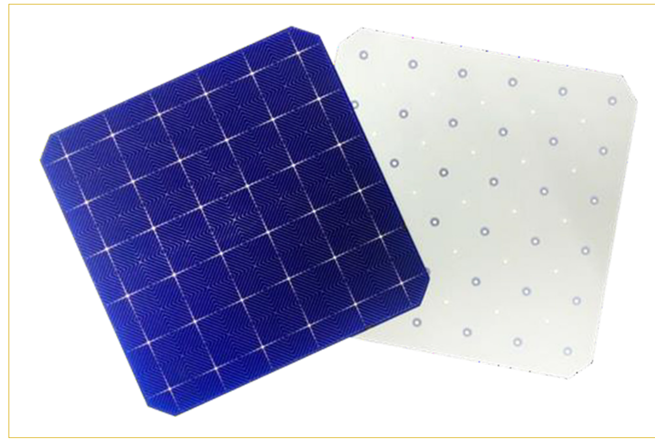


Figure 5: Structured Foil Technology

More and more of PV is specifically designed for certain environmental conditions. Desert conditions yield an extremely good source of solar power. Location decisions will depend on latitude, cloud cover, aerosols, elevation, and shading factors. Optimal sites will have a combination of factors including a latitude close to the equator, low average cloud cover, low aerosols/pollution presence, high elevation to reduce atmospheric absorption, and minimal shading.

Figure 6: PV Specifically Designed to Withstand Extreme Desert Conditions

Special PV modules need to be created in order withstand harsh conditions. In Figure 6, the Atacama Desert has the highest UV radiation on the planet and also very big temperature changes during the day, so very rugged and dependable PV modules were created.

OTHER PVS CURRENTLY IN DEVELOPMENT

Figure 7: Self-Charging Solar Power Cars such as Sion from Sono Motors in Germany

Vehicles can be encased in solar panels which allow them to self-charge. One such example is Germany's Sono Motors, whose Sion vehicle can drive 25 miles / 40 kilometers per day, without recharging[7]. The technology has potential for future use in buses, trucks, trains, and even boats.

Figure 8: Road-integrated PV

Noise protection barriers combine the function of blocking unwanted sound and generating energy. These solar cells convert sunlight into electricity on both sides and the vertical installation inspires new infrastructural possibilities.

Figure 9: PV in Agriculture known as Agrivoltaics

As solar panels heat up, their efficiency decreases. As seen in figure 9, by cultivating crops underneath the PV panels, researchers are able to reduce the temperature of the panels[8].

Figure 10: Floating PV Technology

A (PV) system is placed directly on top of a body of water, as opposed to on land or on the rooftop of a building. This trend is taking off in Singapore and the Netherlands.

Building Integrated PVs are increasingly used in construction design and planning. They can be incorporated into walls and roofs or even retro-fitted. They can be connected to the power supply of the building itself. Urban-integrated photovoltaics are also on the rise with PVs finding new purpose in urban infrastructure such as bus stops, sidewalks and parks and being connected directly to the power grid.

This market expansion leads to a broad diversification in PV module technology. A solar panel is of course a layering of many different advanced materials, and each material may require a unique set of analytical tools in order to accurately analyze and predict properties for optimal solar power generation and longevity.

ICP-MS is used for elemental purity analysis, such as testing for the purity of silicon, while UV/Vis/NIR is used to analyze the reflective and other properties of glass and glass coatings. Polymeric materials which underpins the durability and long-term use of cells, and including those encapsulated in PV layers, can be examined using a range of analytical techniques, from thermal analysis to infrared and hyphenated solutions. Indeed, FT-IR and FT-IR imaging are a perfect extension of UV/Vis/NIR analyses.

The advance of organic photovoltaics (OPV) relies on the development of polymer semiconducting materials. Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) have been indispensable scientific tools for polymer research. In the case of dye-sensitized solar cells-the performance degradation has been a big concern. DSC or TGA can be used to study these degradation mechanisms[9].

Typical analytical applications in the solar industry

UV/Vis/NIR

- Measure Silicon Wafers/Cells
- Optical Characterization of Glass, Encapsulant, Backsheet and Reflectors
- Aging Behavior
- Characterization of Nanomaterials

Differential Scanning Calorimetry

- Measurement of Polymer Encapsulants
- Analysis of Battery Active Layer Materials
- Curing Determination of EVA
- Degree of crosslinking of solar cell encapsulants
- Study of Epoxy Materials
- Degradation Studies of PET Backsheet Material

Thermogravimetry

- Characterization of Polymers using TGA
- Adhesive Characterization using TG-IR
- Determination of EVA using TG-IR and TG-GC/MS
- Characterization of Novel POE & TPO Encapsulants
- Thermal Degradation Studies of PV Encapsulants

FTIR & FTIR Microscopy

- Development of Advanced Polymers by FT-IR/NIR
- Measurement of Silicon Wafers/Cells at Ambient/ Subambient Temperatures
- Determination of Infrared-Optical Properties of Polymer Films
- Raw Material Identification
- Impurity Measurements
- Identification of chemical degradation products of polymers

Elemental Analysis

- Determination of Silicon Purity by ICP-OES or ICP-MS
- Purity/Impurities of Different Materials by ICP-OES or ICP-MS
- Purity/Impurities of Chemicals Used in Manufacturing

Source available for download here

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Researchers will continue to study the laminated multi-layer polymeric films widely used in PVs to determine characteristic values for material failure. The main objective of this systematic investigation of the effect of specimen preparation of laminated multilayer films on the accelerated weathering test results is to create more durable modules with even longer service lifetimes[10].

Thermal analysis and hyphenated technologies, like TG-IR, TGA-GC/MS, or TGA-IR-GC/MS provide ultimate flexibility in testing – and different types of material information can be obtained from a single measurement.

Keep Learning - click here to watch a presentation on advanced analyses techniques; from optical characterization of cover glass to variable angle spectroscopy and material characterization of PV polymers.

https://www.perkinelmer.com/library/chasing-the-sun-advanced-analysis-for-innovative-pv-materials.html

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