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CHEETAH

Cost-reduction through material optimisation and Higher EnErgy outpuT of solAr pHotovoltaic modules - joining Europe's Research and Development efforts in support of its PV industry

Deliverable

D5.9 - Guidelines for standards for next generation PV technologies

WP5 – Acceleration of innovations' implementation

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Section 3 – Publishable summary

Description of the deliverable content and purpose

This report constitutes the propositions of the Cheetah project for Guidelines for standards for next generation PV technologies.

Standards are an effective means of cementing the benefits of innovation and promoting the development of an open market. These are complemented by a range of characterisation measurements which may be applied to the final product or a component at an intermediate stage of the overall production process. Some of these are standardised, while for others a consensus "best practice" approach is adopted. Standards also have an important role in ensuring product quality, in manufacturing, design, installation, operation and end of life management.

The broad membership of the Cheetah project and the deep experience of the partner organisations provided a unique opportunity to assess standards issues relevant to innovative PV technologies and the associated pre-normative research needed to address these.

The research work carried in the Cheetah project itself produced several results relevant to new and improved standards:

- Solar simulators with variable illumination intensities (electrical performance)
- Best practice X-ray refraction techniques for CIGS (diagnostics)
- Thin film multi-junction power measurement (electrical performance)
- Characterising degradation of OPV/DSSC/PSC devices under controlled environmental conditions (reliability/diagnostics)

Section 4 - Guidelines for standards for next generation PV technologies

1. Introduction

This report constitutes Deliverable 5.9 of the Cheetah project and falls under Work package 5, Task 5.3: Guidelines for standards for next generation PV technologies.

Standards[1] are an effective means of cementing the benefits of innovation and promoting the development of an open market. These are complemented by a range of characterisation measurements which may be applied to the final product or a component at an intermediate stage of the overall production process. Some of these are standardised, while for others a consensus "best practice" approach is adopted. Standards also have an important role in ensuring product quality, in manufacturing, design, installation, operation and end of life management. [2]

R&D and industrial organisations have an important role to play in the development of standards for new technologies, both at a pre-normative stage and working in the technical committees of national, European and international standards organisations. In this context the Cheetah project has a double interest: a) some of the results from the research programme and from coordination activities may be relevant to improving existing standards or setting the basis for new ones, and b) as a group representing many of leading European research organisations, it has special insight on possible standards issues for innovate PV technologies and the associate pre-normative research needed to address these. This report covers the following aspects:

- Overview of the currently active standards bodies;
- Results of 2 surveys regarding the coverage of standards and best practices, and priorities for development;
- Analysis Cheetah project research relevant or potentially relevant to standards (KPI 5.3: "Number of contributions to standards and standardisation processes resulting from Cheetah")
- Discussion on areas for coordinated action.
- Conclusions.

[1] The European standards bodies define a standard as a document, established by consensus and approved by a recognized body that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context. Standards should be based on consolidated results of science, technology and experience, and aimed at the promotion of optimum community benefits.

[2] PV ETIP Report 2017 "Development of the European PV Industry and Markets through Enhanced Quality"

2. PV Standards Bodies and Standards Related Activities

2.1. International Electrotechnical Commission (IEC)

The IEC is the partner organisation of ISO and forms together with the International Telecommunication Union (ITU) the United Nations related, world-wide standardisation process. IEC is entrusted with all standards aspects in the electrotechnical field, and was founded in 1904. Membership is required for all countries which are part of the World Trade Organisation (WTO) as commitment to remove international trade barriers, but is also open to all other United Nations members.

2.1.1. Technical Committee 82: Solar Photovoltaic Energy Systems

TC 82 was established in 1981. Since then it has published more than 103 Standards and Technical Specifications, which laid the foundation for the strong increase of trade for PV products. IEC TC 82 has currently 51 member states (40 Participating countries and 11 Observer countries). Its scope is to prepare international standards for systems of photovoltaic conversion of solar energy into electrical energy and for all the elements in the entire photovoltaic energy system. In this context, the concept "photovoltaic energy system" includes the entire field from light input to a photovoltaic cell to and including the interface with the electrical system(s) to which energy is supplied. TC 82 runs the following working groups and project teams:

- WG 1 Glossary
- WG 2 Modules, non-concentrating
- WG 3 Systems
- WG 6 Balance-of-system components
- WG 7 Concentrator modules
- WG 8 Photovoltaic (PV) cells
- PT 62994-1 Environmental Health and Safety (EH&S) Risk Assessment for the sustainability of PV module manufacturing - Part 1. General principles and definition of terms
- PT 63092 Building Integrated Photovoltaics (BIPV)

It also participates to the following Joint Working Groups with other TCs:

- JWG 1 Photovoltaic off grid systems, including decentralized rural electrification and hybrid systems
- JWG 10 Distributed Energy Resources Interconnection with the Grid (managed by TC 8 System aspects for electrical energy supply)
- JWG 4 Grid code compliance assessment for grid connection of wind and PV power plants (managed by SC 8A)
- JWG 82 TC21/TC82 - Secondary cells and batteries for Renewable Energy Storage (managed by TC 21)
- JWG 32 Electrical safety of PV system installations (managed by TC 64)

2.2. IECRE

The IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications (IECRE System) was formed in 2014 to define how certificates can be issued at system level for 3 sectors: wind, solar and marine energy. Each consists of complex arrangements of sub-systems including structures, which are usually installed outside of any protective environment and whose reliability and performance is affected by direct interaction with the natural environment.

Conformity assessment can be performed and certificate issued for an individual PV power plant on a specific site at various stages of its design and implementation (see Figure 1). It aims to give confidence that a PV plant will safely perform as promised and reduce cost at the same time. It represents as step beyond standards, in that while IEC writes technical standards, IEC does not define how these are used.

The IECRE Specific Certificate Categories can include:

- PV Site Qualification certificate
- PV Power Block design qualification certificate
- PV Plant Design qualification certificate
- Conditional PV Project certificate (construction complete / commissioning)
- Annual PV Plant Performance certificate
- PV Asset Transfer certificate
- PV Decommissioning certificate

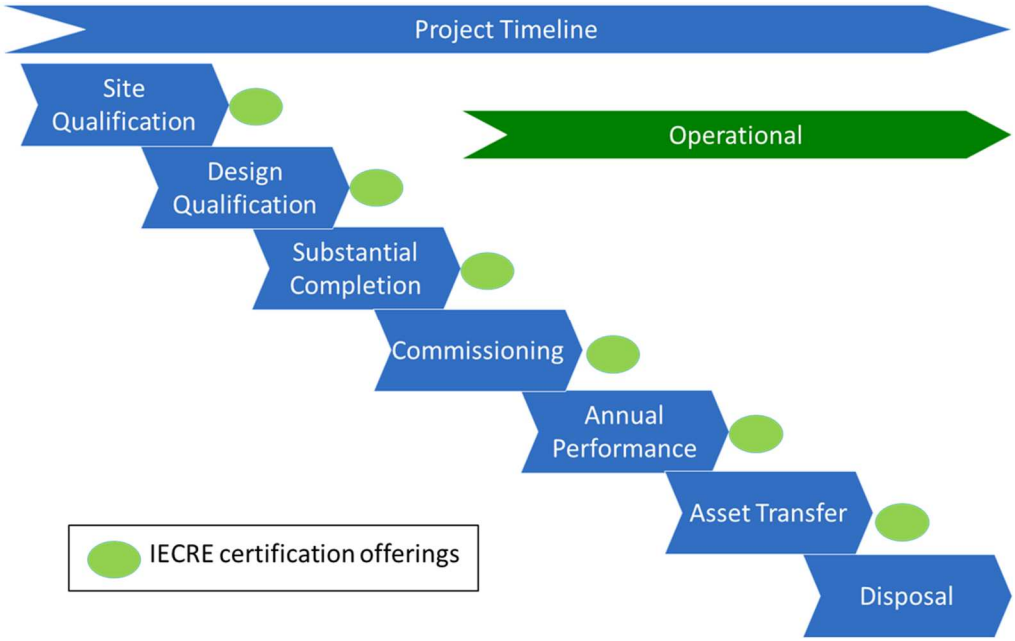

Figure 1 IECRE system timeline view

2.3. CEN/CENELEC

CEN, CENELEC and ETSI all have a European Union mandate for development of standards in relation to the completion of the internal market. The specific mandate for standardization in the field of solar photovoltaic energy systems and components is M/089 EN. This is implemented by CENELEC (the European Standards Organisation in the electrotechnical field) Technical Committee 82: Solar Photovoltaic Systems.

Under the terms of the Frankfurt Agreement, CENELEC also transforms IEC standards into European standards, usually in a "fast track" procedure of 2 months, keeping the IEC document numbers. CENELEC together with the European National Committees (EU28 + EEA) also fosters translation into national languages. The Frankfurt Agreement includes a mutual requirement of notification of standards work, and the commitment by either party to not engage in topics if the other party is already doing it.

CENELEC TC 82 is organized in two working groups. WG 1 works on standards for wafers, solar cells and terrestrial photovoltaic modules and for related components. WG 2 addresses standards for balance of systems (BOS) components, interfaces of PV systems and system integration. The standards are in the general areas of electrical performance, environmental testing, quality assurance and assessment criteria.

Also of relevance is CEN TC 371 "Project Committee - Energy Performance of Building project group". This is responsible for the overarching standard ISO EN 52000 series concerning building energy performance and therefore encompassing building integrated PV products.

2.4. Other standards organisations

2.4.1. ASTM International

ASTM International, formerly known as the American Society for Testing and Materials (ASTM), develops international standards. Technical committee E44.09 Photovoltaic Electric Power Conversion is dedicated to development of standards for PV.

2.4.2. SEMI

SEMI is the global industry association serving the manufacturing supply chain for the micro- and nano-electronics industries. The charter of Global Photovoltaic Materials Committee is:

Explore, evaluate, discuss, and create consensus-based standard measurement methods, specifications, guidelines, and practices that, through voluntary compliance, will promote mutual understanding and improved communication between users and suppliers of photovoltaic materials and related metrology equipment to enhance the manufacturing efficiency and capability so as to reduce manufacturing cost of the photovoltaic (PV) industry.

2.4.3. International PV Quality Assurance Task Force

PVQAT (PVQAT, pronounced as "PV cat") aims to aid the development of standards that allow stakeholders to quickly assess a module's ability to withstand regional stresses, thereby reducing risk and adding confidence for those developing products, designing incentive programs, and determining private investments. It's primary goals are to develop:

1. A rating system to ensure durable design of PV modules for the climate and application of interest.

2. A guideline for factory inspections and quality assurance (QA) during manufacturing.

3. A comprehensive system for certification of PV systems, verifying appropriate design, installation, and operation.

PVQAT now has 13 individual task groups focused on accelerating progress toward implementing these three approaches. Several hundred volunteers from around the world contribute to these and they have already made significant contributions to the standardisation activities. Indeed in 2017 PVQAT attained a type A liaison with IEC TC82 to enable a close co-ordination of its work programme with standardisation activities.

2.4.4. European Cooperation for Space Standardization

The European Cooperation for Space Standardization (ECSS) is an initiative designed to develop a coherent, single set of user-friendly standards for the European space community, which means ESA, its member states and their space industry. Its standard ECSS-E-ST-20-08C (2012) outlines the requirements for the qualification, procurement, storage and delivery of the main assemblies and components of the space solar array electrical layout: photovoltaic assemblies, solar cell assemblies, bare solar cells, cover glass and protection diodes. It is divided into five specific subjects, each one corresponding to each assembly or component:

• Clause 5 defines requirements for photovoltaic assemblies,

• Clause 6 for solar cell assemblies,

• Clause 7 for bare solar cells,

• Clause 8 for cover glasses,

• Clause 9 for protection diodes.

Two additional clauses are dedicated to sun simulators and calibration procedures (clause 10 and capacitance measurement methods (clause 11).

2.4.5. International Summit on OPV Stability

ISOS has been running since 2008 and has become one of the most attended workshops in the field, bringing together an expert community both from industry and academia. ISOS meetings are held yearly and have led to numerous publications, including the so-called ISOS testing protocols for characterization of solar cell durability. The procedures include directions for shelf life testing (D), outdoor testing (O), laboratory weathering testing (L) and thermal cycling testing (T). These procedures are not meant to be

product qualification tests, but rather generally agreed test conditions and practices to allow ready comparison between laboratories and to help improving the reliability of reported values. Failure mechanisms and detailed degradation mechanisms are not addressed.

2.5. Summary of Existing Standards and Best Practices

Annex 2 provides a catalogue of the various standards and best practices related to photovoltaic components, most stemming from the organisations and activities described in the sections above. For the purpose of this synthesis, four themes are used:

- Materials, processing and manufacturing
- Electrical performance of PV Devices (Cells and Modules)
- Module safety, reliability and lifetime;
- Systems.
- Integrated Applications

3. Priorities for New and/or Improved Standards

3.1. Internal Cheetah Survey 2015/16

In late 2015 a survey was conducted in the Cheetah consortium itself, addressing 4 main categories of materials, processing and manufacturing; electrical performance; reliability and lifetime and systems. These divided into sub-categories and for each of these respondents were asked to identify their priorities from a pre-defined list, or suggest something else. Table 1 shows the overall scheme.

34 responses were received and the 2016 Deliverable D5.8 (delivered 2016) describes the results and analysis in detail. Priority areas for developing new/improved standards and best practices included:

Materials, processing and manufacturing

Defect measurement and detection was given the highest priority overall, followed by surface and interface properties. In terms of technology sector, the OPV, DSSC, perovskite group was prioritised.

Electrical performance

The "OPV, DSSC, perovskite" group was the most cited technology sector, followed by thin film concepts. In terms of priorities, energy yield/rating was of highest concern across all the technology sub-categories. However for the individual sectors the situation is different: "calibration at STC" received highest (or joint highest) scores for TF, multijunction, III-V and bifacial devices, while "stability and preconditioning" was (joint) highest for TF and OPV/DSSC/PSC sectors.

Reliability and Lifetime

The top three scoring items were lifetime tests, encapsulant properties and "humidity, temperature and voltage" testing.

Systems

BIPV and rooftop emerge were the most frequently prioritised system sub-categories. In terms of overall scores for priorities across all the sub-categories, the most noted was recycling, followed by operation and maintenance and then smart grid interfaces.

Exactly 50% of the respondents expressed interest in contributing to work on best practices and standards as part of Cheetah networking activities. The areas of interest were however relatively diverse, but OPV/DSSC/PSC, defect detection and spectroscopy are common to several respondents.

Table 1 Scheme for the 2015/16 internal Cheetah survey on priorities for standards.

Category	Sub-Category	Possible Priority Items (for each sub-category)
Materials, processing and manufacturing	advanced cSi CI(G)S, CdTe, TF-Si III-V devices OPV, DSC, PSC	Chemical properties e.g. trace element measurement Physical properties including dimensions grain size roughness Surface and interface properties Spectroscopy Capacitance techniques Scanning defect mapping Reflectance & refraction Etching Scribing Defect measurement and detection Handling
Electrical performance	advanced cSi CI(G)S, CdTe, TF-Si III-V devices OPV, DSC, PSC multi-junction bifacial	Power Calibration @ STC Stability and Pre-Conditioning Spectral Response Temperature Sensitivity Shading Effects Energy yield/rating On-board electronics
Reliability and lifetime	[no sub-categories used]	Damage Detection and Measurement Thermal & Mechanical Fatigue Including Vibration Humidity, Temperature, & Voltage Diodes, Shading, & Reverse Bias Potential induced degradation UV Corrosion Hail Dust and soiling Snow & Wind Loading Glass properties Encapsulant properties Junction Box Connectors On-board electronics Lifetime tests Datasheets/Labelling Type approval/design qualification
Systems	Rooftop Free-standing BIPV Stand-alone PV + storage PV + heat pump	Electrical performance Electrical safety Structural safety Performance monitoring Balance of systems requirements Trackers Inverter requirements Smart grid interfaces Life cycle analysis Recycling

		Operation and Maintenance System design and installation

3.2. Stakeholder Survey 2017

In September 2017 the Cheetah Project ran a survey on "Priorities for Standards and Best Practices". This report gives an overview of the results. The EU Survey software tool was used to manage the questionnaire, which was in English only. The distribution was via emails with an internet link to the survey, and covered:

- Cheetah project participants
- Solar Power Europe (approximately 700 individual emails).
- European Technology Innovation Platform for PV
- European Energy Research Alliance PV group

While the structure was kept simple, following the recommendations from the 2015/16 survey, it addressed the full value chain and a broad range of applications. Table 2 shows the categories and priority options ("no reply" or "other" was also permitted). Overall 57 replies were received. Overall, the effort to obtain a broad participation by distribution to Solar Power Europe members was fairly successful; the 2015 survey had been restricted to the Cheetah partners themselves, and so sampled only the research community. To reflect this in the analysis, we considered also two sub-groups: "industry", comprising the fields "industry", "services" and "consultants" (23 replies), and "research" comprising the remainder (33 replies).

At the start of the survey the respondents were asked about their level of satisfaction with current standards. Although a sizeable majority of 74% found this to be "satisfactory, but with scope for improvement and/or new initiatives, 19% replied "unsatisfactory, important issues need to be addressed". Only 7% replied "very satisfactory, no major gaps".

The results are detailed in a dedicated report[3]. Highlight for the main categories include:

3.2.1. PV Cells and Modules

The theme most frequently indicated as a priority was "reliability, degradation and lifetime", while "power/energy performance" was second. There was also significant interest in sustainability and recycling. The distribution of the replies from the industry and research sub-groups is quite similar in this case.

The respondents gave design type approval (certification) the lowest priority score, suggesting that many don't see explicit shortcomings in existing procedures for ensuring an adequate level

[3] N. Taylor, M. Heisz, E. Roman, 2017 Survey of Standards for Priorities for Standards and Best Practices: Quick Look Report, JRC 108849

of production quality for the standard flat-plate products that comprise the bulk of the market (indeed the new IEC 61215 type approval standard was published in 2016).

In relation to power energy performance, the areas of concern were for bifacial modules and in general for "3rd generation" devices, with DSSC and perovskites also specifically mentioned. This raises a well-known issue regarding the extent to which standards reflect the different characteristics of underlying PV technologies, as opposed to restricting themselves to product functionality. Up to now the IEC and CENELEC committees have largely focused on a single functionality i.e. flat plate PV modules and systems for long-term outdoor energy production. If some technologies aim to address other applications, there may well be a case for dedicated standards. This theme also comes up under the area for "other applications".

3.2.2. Inverters

Relatively few respondents (14%) indicated inverters as a main activity, but a substantial number replied to this question. Overall, the theme "reliability, degradation and lifetime" was most frequently indicated as a priority, while "grid support functions" and "integrated storage functions" also received high scores.

The industry sub-group gave more emphasis to standards for grid support function and to integrated storage functions. This may well reflect the growing awareness and interest in interoperability issues. Indeed the additional comments drew attention to the potential role of smart meter standards. Also one respondent noted "failure detection", hinting at the possibilities for increasing sophistication in operational feedback from a system or plant.

3.2.3. Trackers

Relatively few respondents indicated this as an area of specific interest. The main item of concern was standards for reliability, degradation and lifetime, with design type approval second. The interest in reliability was further emphasized in the comments, which noted issues such as: wind tunnel testing, harsh conditions and combined tracker and module cleaning functionality. Type approval and power/energy use were also cited by many. The ranking of priorities for the industry and research sub-groups was similar.

3.2.4. Building Integrated Products

The theme most frequently indicated as a priority is "reliability and lifetime". Given the high priority already assigned to this theme for modules, it's understandable that it's also seen as critical for this application, where durability expectations are high and repair/replacement is often non-trivial operation. Overall the 2nd ranked priority was "system functionality and performance", although the industry replies gave this as top ranking issue, slightly ahead of reliability and lifetime.

Although "design type approval" only scored 5th highest as priority, several comments were made on related issues such as:

- BIPV specific conditions, in particular higher running temperatures
- Widely varying design requirements requiring recertification for each new version
- Need to address non-glass substrates (the current EN standards are limited to glass-glass elements)
- Addressing products with module level electronics
- More flexible process to accommodate innovative products

3.2.5. Systems

The areas "operational monitoring and degradation" and "power and/or energy performance" were joint highest priority, with scores almost twice that of the other issues. "Maintenance" and "design requirements" received the lowest support. For this question there were several differences in the replies of the industry and research sub-groups: the industry respondents ranked "power and energy performance" as top priority, followed by "resource assessment /forecasting " and "design requirements", with "operation monitoring and degradation" only fourth.

The respondents provided relatively few comments, but the highlighted issues included:

- Design Requirements: calculation standards for self-consumption performance
- Resource Assessment: short-term <1 hour;
- Power/Energy requirements: short-cycle storage (< 1 hour), ramp-times etc,
- More accurate determination of PV system degradation phenomena, and its impact in the energy yield during its lifetime.

In regard to safety, the only specific indication was for measures against and in case of fire. Given the high apparent concern about operational monitoring, it is surprising there were no specific comments on how standards could be applied in this area.

3.2.6. Integrated Applications

The replies received indicated a strong interest in PV for electric vehicles. Indeed the IEA PVPS programme is considering setting up a task on vehicle integrated PV, which would be a useful focal point for activities in this area. Many of the respondents also saw "energy harvesting for autonomous devices" as a priority theme for standards. Roads and paths received some interest, but sound barriers and wearables rather less. The industry and research sub-groups had very similar priorities.

Table 2 Scheme for the 2017 Cheetah survey on priorities for standards.

Category	Possible Priorities
PV Cells and Modules	Design type approval (certification) Module level electronics Sustainability (environmental footprint) Recycling Innovative cell concepts (materials or electrical configuration) Materials, processing and manufacturing Power/energy performance Reliability, degradation and lifetime
Inverters	Recycling Design type approval (certification) Sustainability (environmental footprint) Maintenance Power/energy performance Intergated storage functions Grid support functions Reliability, degradation and lifetime
Trackers	Design type approval (certification) Power/energy use Recycling Reliability, degradation and lifetime Sustainability (environmental footprint)
Building Integrated Products	Component energy performance Component structural performance Design type approval (certification) Recycling Reliability and lifetime Sustainability (environmental footprint) System functionality and performance
Systems	Design Requirements End of life management Maintenance Operational Monitoring and Degradation Detection Power and/or Energy Performance Requirements Resource Assessment / Forecasting Safety Requirements Sustainability (environmental footprint)
Integrated Applications	Electric Vehicles Energy harvesting for autonomous devices (Internet of Things) No reply Roads and Paths Sound barriers Wearables

4. Cheetah Results Relevant to Standards

Support to the development or improvement of standards is an important project outcome, as recognized by the KPI 5.3: Number of suggested possible contributions to standards and standardization processes resulting from CHEETAH. This section reviews the key exploitation results (KERS) and other networking activity results from this point of view. Table 3 shows the analysis.

Table 3 Potential impact of Cheetah project research results for new and/or improved standards.

Cheetah Item/Result	Lead Org.	Potential Relevance to New or Improved Standards	Relevant Committee	KPI 5.2 (Y/N)
Online OPV lifetime database	DTU	Useful data for benchmarking stability	ISOS IEC WG 2	N
Development of chemical etching treatment of CZTS monograin powders surface	TUT	Technical procedure	N/A	N
Solar simulator with illumination intensities variable from 0.1 - 100 suns	**HZB**	**Updates to 60904-9-1 collimated bean solar simulator requirements**	**IEC WG2/7**	**Y**
Know-how for processing thin cells on a heterojunction solar cell pilot line	CEA	Technical procedure for manufacturing	N/A	N
Process and know-how for making porous silicon stacks that allow the growth of high-quality epitaxial silicon layers and subsequent high-yield detachment of large-area silicon foils	IMEC	Technical procedure for manufacturing	N/A	N
Adapted process for making porous silicon stacks that allows the growth of high-quality epitaxial silicon layers in an in-line high-throughput reactor and subsequent detachment of large-area silicon foils	IMEC and ISE	Technical procedure for manufacturing	N/A	N
Development of low-temperature annealing treatment for optimization of disordering level in CZTS monograins	TUT	Technical procedure	N/A	N

Cheetah Item/Result	Lead Org.	Potential Relevance to New or Improved Standards	Relevant Committee	KPI 5.2 (Y/N)
Subwavelength characterization of optoelectronic devices by scanning near-field optical microscopy combined with rigorous optical simulations	Jülich	Combined measurement and simulation procedure	N/A	N
Procedures and know-how for characterisation of degradation of PV devices under controlled environmental conditions	**NPL**	**Pre-normative know-how for reliability testing of consumer products using OPV/DSSC/PSC**	**ISOS/ IEC WG 2**	**Y**
Characterisation of environmental characteristics of unique large portable test chamber	NPL	Linked to previous item		
Know-how for integration of thin cells into modules (back contact/smart wire)	ECN and CEA	Technical procedure for manufacturing	N/A	N
Thermomechanical model for back contact PV module (ISE)	ISE	Modelling technique (best practice)	N/A	N
XRF CIGS techniques round robin	**EMPA**	**Research technique best practice**	**IEC**	**Y**
Thin film power measurement round robin	**HZB/JRC**	**Need for guidance on MJ SR techniques and stability relevant to 60904-1-1 and 60904-8-1**	**IEC WG 2**	**Y**
Perovskite power measurement round robin (part of Cheetah?)	DTU	?		
Imaging and inspection techniques white paper (in preparation?)	AIT		IEC	

5. Discussion

The two surveys have identified a number of priorities about needs for new or improved standards. In the following section we address some selected issues in relation to the status of the existing body of standards, also with the aim of identifying the type of actions that could be undertaken by European research organisations.

5.1. Reliability, Defect Detection and Characterisation, Lifetime

These areas were highlighted as a top priority in both the 2015/16 and 2017 surveys. The underlying issues are complex[4], with technical challenges at three levels[5]:

1. How can we determine that a module design is adequate for the warranty?
2. How can we ensure that modules coming off the production line reflect the intended design?
3. How can we ensure that the entire system is put together and functioning correctly?

There is an already extensive body of standards in place, making progress requires a continuous effort on specific aspects of design, materials, manufacturing, installation, operation and end-of-life management. Design type approval and qualification (intended to ensure low failure rates in the PV products entering service) has been a focus of IEC TC 82 from the beginning. In recent years IEC TC 82 has given increasing attention to the second aspect, whereas the new IECRE approach addresses overall system quality. The International PV Quality Assurance Task Force (PV-QAT) task groups provide an increasingly significant pre-normative technical input to IEC TC 82.

A revision of the 2016 PV type approval standard IEC 61215 Parts 1.1, 1-2, 1-3 and 1-4 is already underway. The revisions are foreseen to incorporate the specific issues of testing flexible PV modules and bifacial modules. Additional tests may be incorporated to cover specific failure modes (for example PID).

Many of the comments received in the surveys made reference to the need for "lifetime tests", particular for modules but also for other components such as inverters and trackers. Manufacturers are increasingly using long-term degradations rates as a marketing tool for modules, but as yet there are no standard tests to substantiate these claims in reliable and transparent way. Realisation of a "lifetime test" concept presumes ex ante knowledge of both the operational environment and of the possible degradation or failure modes, either at

[4] See for instance Cheetah D5.5 "Benchmark Knowledge of the Quality and Reliability of PV Technology, 2017

[5] T. Sample, "The Necessity for PV Standards in Reliability and Performance", 2nd Annual Workshop on the Integration of Photovoltaics in the Mediterranean Electricity Markets, Ispra, November 2017

component or system level. Once the driving force for the failure mode has been identified, accelerated stress tests can be designed to cause the same failure mode to occur in a shorter time. Up to now, this hasn't been feasible, but significant efforts have been on key aspects:

- Collection and sharing of field experience on degradation and failures, for instance in the framework of IEA PVPS Task 13.
- Improved methods for monitoring and quantifying degradation
- Investigation of specific reliability tests, particularly for modules and considering also combined effects (e.g. UV and thermal cycling).

From an EU perspective, the new SET-Plan TWP PV Implementation Plan (October 2017) includes the objective to achieve a "further enhancement of lifetime, quality and sustainability and hence improving environmental performance". Under this theme a key goal is to "maintain proven system energy output per year at least 80% of initial level for 30 years by 2020 and for 35 years by 2025". There is now a need to formulate a detailed strategy to address:

- - Priorities for EU pre-normative research on reliability and lifetime issues
- - Effective coordination of efforts on these issues at European level, including optimizing the sharing and use of operational degradation data
- - Effective coordination with initiatives at international level.

5.2. Digitisation

Industry respondents to the second survey noted the need for standards for grid support functions for inverters, as well as for integrated storage functions.

Already considerable efforts are being made for smart grid[6] concepts. In 2011 the European Commission issued Smart Grid Mandate M/490, which requested CEN, CENELEC and ETSI to develop a framework to enable European standards organisations to perform continuous standard enhancement and development in the smart grid field. Recently the Coordination Group released two reports summarising the situation:

1.Smart Grid Set of Standards (2017) that proposes an updated framework of standards for smart grid deployment in Europe, and a standardization work program to identify gaps.

[6] CEN/Cenelec website: "*A smart grid is an electricity network that can integrate in a cost-efficient manner the behaviour and actions of all users connected to it (generators and/or consumers) in order to ensure economically efficient, sustainable power system with high levels of quality and security of supply and safety*."

2.Smart Grid Cyber Security & Privacy (2016), addressing security standardization specific to smart energy grids

These draw substantially from the work of the IEC Smart Grid Strategic Group, and the latest version of the IEC Smart Grid Strategic Roadmap was released in 2017[7]. At the same time, non-institutional groups are also taking the initiative; for instance the Smart Buildings Alliance for Smart Cities is developing its own smart buildings standards called ready2Services and ready2Grids.

Indeed the theme of digitisation can impact every stage of the PV value chain and will be essential to the development of successful business models for future large scale deployment and market penetration. A recent SolarPowerEurope report[8] focuses on this theme. In specific relation to standards, it includes the following recommendations:

- *Guarantee that state of the art and up-to-date data protection and cybersecurity standards are put in place.*
- *Ensure that EU-level work on standards and interoperability, within the Digital Single Market includes solar PV systems, smart buildings and smart grids. Encourage the Commission to come forward with its 'baseline' standardised data format as soon as possible, which individual device or service manufacturers will then add additional features to.*

The EC's work programme on standards for 2018[9] also highlights the role of digitization also for the Energy Union, noting *inter alia* the need for "*specific action to target the interconnection of electricity networks, support diversified gas supply streams and integrate renewable energy into the consumption mix*".

5.3. Electrical performance

In this area, the IEC TC 82 has projects relevant to several of the priorities identified in the surveys:

Energy rating of modules: development of the IEC 61853-3 Photovoltaic (PV) module performance testing and energy rating - Part 3: Energy rating of PV modules and IEC 61853-4 Photovoltaic (PV) module performance testing and energy rating - Part 4: Standard reference climatic profiles, is now at an advanced stage and the standards are expected to be published by the end of 2018. This work has also been supported by the Euromet Photoclass project,

[7] IEC TR 63097:2017, Smart grid standardization roadmap

[8] SolarPowerEurope, Digitalisation & Solar Task Force Report, October 2017

[9] COM(2017) 453, The annual Union work programme for European standardisation for 2018

which made significant contributions in relation to procedures for temperature dependence, angular, spectral properties of solar cells, to definition of standard reference climatic profiles) and to improved procedures for uncertainties and traceability.

Power Calibration of Multi-Junction Devices: in 2017 the IEC published IEC 60904-1-1: Photovoltaic devices - Part 1-1: Measurement of current-voltage characteristics of multi-junction photovoltaic devices and IEC 60904-8-1: Photovoltaic devices - Part 8-1: Measurement of spectral responsivity of multi-junction photovoltaic (PV) devices.

Power Calibration of Bifacial Modules: IEC TC 82 WG 2 is currently working on IEC TS 60904-1-2, for measurement of current-voltage characteristics of bifacial photovoltaic devices. The document should be published in 2018.

Power Measurement for OPV, DSSC and PSC devices: The survey replies indicated that specialized measurement procedures for organics, dye sensitised and perovskite devices are not available, particularly if such devices target low light conditions and/or applications for which power generation is not the only function e.g. wearables or self-powered electronic devices. The IEC 61853-1 Part 1 defines a matrix of irradiance and temperature conditions which may provide a better basis for assessing performance for specific applications. It is acknowledged that other issues such as pre-calibration stabilisation requirements remain to be addressed. A compilation of best practice for the characterisation of emerging PV (OPV, polymer based) and slow responding devices is being prepared as an IEC technical report.

System Energy Output: This item was highlighted in the 2017 survey, and has implications not just for ground-based system but it also highly relevant to the building applied and integrated products in relation to defining their contribution to the overall building energy balance. A further issue concerns more accurate determination of PV system energy yield over the operational, taking degradation phenomena into account.

5.4. PV in the built environment

Building integrated PV has long been recognised as an important area, but also one in which the lack of standards is frequently cited as an issue. The publication of the EN 50583-1 (BIPV modules) and EN 50583-2 (BIPV systems) standards in January 2016 was a major step forward. These two standards were passed to the IEC TC 82 via the Frankfurt agreement. A project team is now developing the concepts in an integrated standard IEC 63092-1 and IEC 63092-2, due in 2019. The survey also raised the issue of the cost of design qualification for BIPV components (essentially the same as for standard power generation modules), especially when a wide variety of designs may be needed. It's not clear if IEC intend to take up this issue.

A holistic view is however required for building application. For structural performance, compliance is required with Eurocodes under the Construction Products Directive and Regulation. For energy performance, buildings need to meet the requirements of the Energy

Performance of Buildings Directive. The overall EPB requirements are now set out in ISO 52000-1 (2017). The calculation of the PV energy contribution is covered by EN-15316-4-3:2017 "Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-3: Heat generation systems, thermal solar and photovoltaic systems". Section 6.2 of this latter document sets out a method for calculating the annual electrical energy output, $E_{el;pv;out}$.

$$E_{el;pv;out} = E_{sol} . P_{pk} . f_{perf} / I_{ref}$$

Where E_{sol} is the annual hemispherical solar irradiation on the photovoltaic system, determined by the horizontal irradiation multiplied by a factor f_{tilt} to take account of the angle and orientation of the sytem; P_{pk} is the peak power [kW], f_{perf} is the system performance factor and I_{ref} is the reference solar irradiance equal to 1000 W/m2. The method can also be used in hourly or monthly time steps. It is noted that tables for f_{tilt} and f_{perf} shall be made available at national level, but it is not clear to what extent this has been implemented up to now. Also, member states may create additional regulation on BIPV through their National Building Codes.

Overall, while the EPD requirements establish a framework, many details need to be clearly defined (e.g. system performance factors and degradation effects) and implemented in appropriate tools for the building industry.

5.5. Sustainability

The issue of sustainability was identified as a medium priority across all the thematic areas in the 2017 survey. This fits with the efforts at EU level to promote sustainable product policies, also in the energy sector. For PV, the new SET-Plan Implementation Plan highlights the perform focused research and apply and progress eco-design requirements in preparation of implementing measures supporting maximum energy yield (kWh/kWp) and lowest life-cycle environmental impact.

Photovoltaic electricity generation was included in the 2013-2016 Product Environmental Footprint pilot phase. This had three main objectives:

- test the process for developing product- and sector-specific rules;
- test different approaches to verification;
- test communication vehicles for communicating life cycle environmental performance to business partners, consumers and other company stakeholders.

The Ecodesign Working Plan 2016-2019 includes studies on the energy savings potentials of several energy-related products, including solar panels, inverters and systems. The JRC is now carrying out a preparatory study for Ecodesign, Energy label, EU Ecolabel and Green Public Procurement (GPP) for solar photovoltaic modules, inverters and systems. This will run for 2

years, until autumn 2019. Stakeholder involvement is very important, and three dedicated meetings are foreseen, the first in May 2018. The study is expected to take on board work already done at national level in several member states.

6. Conclusions

The R&D community has an important role to play in the development of standards for new technologies, both at a pre-normative stage on developing best practices and recommendations and by working in the technical committees of national, European and international standards organisations.

The broad membership of the Cheetah project and the deep experience of the partner organisations provided a unique opportunity to assess standards issues relevant to innovative PV technologies and the associated pre-normative research needed to address these. To support this process, online surveys were carried out in 2015/16 and 2017. According to the most recent (2017) survey, a sizeable majority (74%) consider the current status of standards for PV to be "satisfactory, but with scope for improvement and/or new initiatives", whereas only 9% replied "unsatisfactory, important issues need to be addressed".

The respondents see "reliability degradation and lifetime" as key priority for all components and indeed for systems. Considerable work is underway on these complex themes, in particular in the scope of the International PV quality Assurance Forum (PV-QAT). There is a need in Europe to formulate a strategy for pre-normative work and to better coordinate efforts and resources over a broad area encompassing reliability, degradation characterisation and diagnostics.

Standards for building integrated products were also flagged by a significant number of respondents, highlighting issues such as system functionality and performance, compatibility with construction codes and the need to avoid frequent (and expensive) design re-certification. In this case, efforts are particular needed to find efficient and cost effective ways of implementing the requirements of Energy Performance of Buildings Directive, of Eurocodes and of supplementary norms applied by individual Member States.

The issue of sustainability was identified as at least a medium priority across the thematic areas. This may well reflect the growing interest in green procurement and circular economy policies in the EU, as well as the newly launched European Commission preparatory study on Ecodesign to PV modules, inverters and systems.

The research work carried in the Cheetah project itself produced several results relevant to new and improved standards (KPI 5.2):

- Solar simulators with variable illumination intensities (electrical performance)
- Best practice X-ray refraction techniques for CIGS (diagnostics)
- Thin film multi-junction power measurement (electrical performance)
- Characterising degradation of OPV/DSSC/PSC devices under controlled environmental conditions (reliability/diagnostics)

7. Annex 1: Summary of Existing Standards and Best Practices for Photovoltaics

This annex catalogues standards for photovoltaic devices and systems. For the purpose of this synthesis, four themes are used:

- Materials, processing and manufacturing
- Electrical performance of PV devices (cells and modules)
- Module Safety, Reliability and lifetime
- Systems
- Integrated Applications

In the case of the CENELEC and IEC standards, the date of issue is reported as well as an indication of the current status e.g. under revision (often as part of the standard maintenance cycle). Item under development are indicated in italics.

For SEMI and ASTM standards, the mentioned documents are considered to be currently valid. The precise version should be checked on the web sites of the respective organisations.

7.1. Materials, Processing and Manufacturing

Property and/or Characteristic	Code	Year of Issue	Status	Title
Materials Specs	SEMI PV3-0310		"current"	Guide for High Purity Water Used in Photovoltaic Cell Processing
	SEMI PV5-1110		"current"	Guide for Oxygen (O2), Bulk, Used in Photovoltaic Applications
	SEMI PV6-1110		"current"	Guide for Argon (Ar), Bulk, Used in Photovoltaic Applications
	SEMI PV7-1110		"current"	Guide for Hydrogen (H2), Bulk, Used in Photovoltaic Applications
	SEMI PV8-1110		"current"	Guide for Nitrogen (N2), Bulk, Used in Photovoltaic Applications
	SEMI PV11-1115		"current"	Specification for Hydrofluoric Acid, Used in Photovoltaic Applications
	SEMI PV12-1115		"current"	Specification for Phosphoric Acid Used in Photovoltaic Applications
	SEMI PV14-0211		"current"	Guide for Phosphorus Oxychloride, Used in Photovoltaic Applications
	SEMI PV16-0316		"current"	Specification for Nitric Acid Used in Photovoltaic Applications
	SEMI PV17-1012		"current"	Specification for Virgin Silicon Feedstock Materials for Photovoltaic Applications
	SEMI PV20-0316		"current"	Specification for Hydrochloric Acid Used in Photovoltaic Applications
	SEMI PV21-1016		"current"	Guide for Silane (SiH4), Used in Photovoltaic Applications
	SEMI PV24-1016		"current"	Guide for Ammonia (NH3) in Cylinders, Used in Photovoltaic Applications
	SEMI PV25-0317		"current"	Test Method for Simultaneously Measuring Oxygen, Carbon, Boron And Phosphorus in Solar Silicon Wafers and Feedstock by Secondary Ion Mass Spectrometry

Property and/or Characteristic	Code	Year of Issue	Status	Title
	SEMI PV26-1016		"current"	Guide for Hydrogen Selenide (H2Se) in Cylinders, Used in Photovoltaic Applications
	SEMI PV27-0316		"current"	Specification for Ammonium Hydroxide Used in Photovoltaic Applications
	SEMI PV30-0316		"current"	Specification for 2-Propanol Used in Photovoltaic Applications
	SEMI PV33-0316		"current"	Specification for Sulfuric Acid Used in Photovoltaic Applications
	SEMI PV36-0316		"current"	Specification for Hydrogen Peroxide Used in Photovoltaic Applications
	SEMI PV37-0912		"current"	Guide for Fluorine (F2), Used in Photovoltaic Applications
	SEMI PV54-0514		"current"	Specification for Silver Paste, Used to Contact with N+ Diffusion Layer of Crystalline Silicon Solar Cells
	SEMI PV58-0115		"current"	Specification for Aluminum Paste Used in Back Surface Field of Crystalline Silicon Solar Cells
	SEMI PV61-0115		"current"	Specification for Framing Tape for Photovoltaic (PV) Modules
Trace Element Measurement	SEMI PV1-0211		"current"	Test Method for Measuring Trace Elements in Silicon Feedstock for Silicon Solar Cells by High-Mass Resolution Glow Discharge Mass Spectrometry
	SEMI PV59-0115		"current"	Test Method for Determination of Total Carbon Content in Silicon Powder by Infrared Absorption After Combustion in an Induction Furnace
	SEMI PV64-0715		"current"	Test Method for Determining B, P, Fe, Al, Ca Contents in Silicon Powder for PV Applications by Inductively Coupled Plasma Optical Emission Spectrometry
	SEMI PV43-0113		"current"	Test Method for the Measurement of Oxygen Concentration in PV Silicon Materials for Silicon Solar Cells by Inert Gas Fusion Infrared Detection Method
	SEMI PV49-0613		"current"	Test Method for the Measurement of Elemental Impurity Concentrations in Silicon Feedstock for Silicon Solar Cells by Bulk Digestion, Inductively Coupled-Plasma Mass Spectrometry

Property and/or Characteristic	Code	Year of Issue	Status	Title
	SEMI PV50-0114		"current"	Specification for Impurities in Polyethylene Packaging Materials for Polysilicon Feedstock
	SEMI PV74-0216		"current"	Test Method for the Measurement of Chlorine in Silicon by Ion Chromatography
Cell colour	SEMI PV65-0715		"current"	Test Method Based on RGB for Crystalline Silicon (C-Si) Solar Cell Color
Finger aspect ratio	SEMI PV66-0715		"current"	Test Method for Determining the Aspect Ratio of Solar Cell Metal Fingers by Confocal Laser Scanning Microscope
Carrier Lifetime	SEMI PV13-0714		"current"	Test Method for Contactless Excess-Charge-Carrier Recombination Lifetime Measurement in Silicon Wafers, Ingots, and Bricks Using an Eddy-Current Sensor
	SEMI PV9-0611		"current"	Test Method for Excess Charge Carrier Decay in PV Silicon Materials by Non-Contact Measurements of Microwave Reflectance After a Short Illumination Pulse
Defect detection and measurement	SEMI PV39-0513		"current"	Test Method for In-Line Measurement of Cracks in PV Silicon Wafers by Dark Field Infrared Imaging
	SEMI PV51-0214		"current"	Test Method for In-Line Characterization of Photovoltaic Silicon Wafers by Using Photoluminescence
	IEC 82/1357/NP		working item	Electroluminesence of PV cells
TCO Haze measurement	SEMI PV31-0212		Reapproved	Test Method for Spectrally Resolved Reflective and Transmissive Haze of Transparent Conducting Oxide (TCO) Films for PV Application
Dimensions and form	SEMI PV41-0912		"current"	Test Method for In-Line, Noncontact Measurement of Thickness and Thickness Variation of Silicon Wafers for PV Applications Using Capacitive Probes
	SEMI PV42-0314		"current"	Test Method for In-Line Measurement of Waviness of PV Silicon Wafers by a Light Sectioning Technique Using Multiple Line Segments
	SEMI PV46-0613		"current"	Test Method for In-Line Measurement of Lateral Dimensional Characteristics of Square and Pseudo-Square PV Silicon Wafers

Property and/or Characteristic	Code	Year of Issue	Status	Title
	SEMI PV71-0116			Test Method for In-Line, Noncontact Measurement of Thickness and Thickness Variation of Silicon Wafers for Photovoltaic (PV) Applications Using Laser Triangulation Sensors
Etch rate	SEMI PV67-0815		"current"	Test Method for the Etch Rate of a Crystalline Silicon Wafer by Determining the Weight Loss
Grain size	SEMI PV52-0214		"current"	Test Method for In-Line Characterization of Photovoltaic Silicon Wafers Regarding Grain Size
Saw Marks	SEMI PV40-0912		"current"	Test Method for In-Line Measurement of Saw Marks on PV Silicon Wafers by a Light Sectioning Technique Using Multiple Line Segments
	SEMI PV68-0815			Test Method for the Wire Tension of Multi-Wire Saws
	SEMI PV70-0116			Test Method for In-Line Measurement of Saw Marks on Photovoltaic (PV) Silicon Wafers by Laser Triangulation Sensors
Surface Roughness	SEMI PV15-0211		Reapproved	Guide for Defining Conditions for Angle Resolved Light Scatter Measurements to Monitor the Surface Roughness and Texture of PV Materials
Glass and Optics	IEC 62805-1	2017		Method for measuring photovoltaic (PV) glass - Part 1: Measurement of total haze and spectral distribution of haze
	IEC 62805-2	2017		Method for measuring photovoltaic (PV) glass - Part 2: Measurement of transmittance and reflectance
	SEMI PV47-0513			Specification for Anti-Reflective-Coated Glass, Used in Crystalline Silicon Photovoltaic Modules
	SEMI PV63-0215			Specification for Ultra-Thin Glasses Used for Photovoltaic Modules
	IEC/TS 62989 ED1		In progress	Primary Optics for Concentrator Photovoltaic Systems

Property and/or Characteristic	Code	Year of Issue	Status	Title
Substrates	SEMI PV4-0311			Specification for Range of 5th Generation Substrate Sizes for Thin Film Photovoltaic Applications
Neutron Activation Analysis	SEMI PV10-0716			Test Method for Instrumental Neutron Activation Analysis (INAA) of Silicon
Ribbons	SEMI PV18-0912			Guide for Specifying a Photovoltaic Connector Ribbon
	SEMI PV19-0712			Guide for Testing Photovoltaic Connector Ribbon Characteristics
Wafer Specs	SEMI PV22-0817			Specification for Silicon Wafers for Use in Photovoltaic Solar Cells
Resistivity / Sheet Resistance	SEMI PV28-0316			Test Method for Measuring Resistivity or Sheet Resistance with a Single-Sided Noncontact Eddy-Current Gauge
Identification/Marking	SEMI PV29-0212			Specification for Front Surface Marking of PV Silicon Wafers with Two-Dimensional Matrix Symbols
	SEMI PV32-0312			Specification for Marking of PV Silicon Brick Face and PV Wafer Edge
	SEMI PV34-0213			Practice for Assigning Identification Numbers to PV Si Brick, Wafer and Solar Cell Manufacturers
	SEMI PV48-0613			Specification for Orientation Fiducial Marks for PV Silicon Wafers
Diffusion Furnace Temp.	SEMI PV53-0514			Test Method for In-Line Monitoring of Flat Temperature Zone in Horizontal Diffusion Furnace
Back-Contact Terminology	SEMI PV62-0215			Terminology for Back Contact Photovoltaic (PV) Cells and Modules
Encapsulants	*IEC 62788-1-1*		*working item 82/1358*	*Measurement procedures for materials used in photovoltaic modules - Part 1-1: Polymeric materials used as encapsulants*
	IEC 62788-1-2	2016		Part 1-2: Encapsulants - Measurement of volume resistivity of photovoltaic encapsulants and other polymeric materials

Property and/or Characteristic	Code	Year of Issue	Status	Title
	IEC 62788-1-4	2016		Part 1-4: Encapsulants - Measurement of optical transmittance and calculation of the solar-weighted photon transmittance, yellowness index, and UV cut-off frequency
	IEC 62788-1-5	2017		Part 1-5: Encapsulants - Measurement of change in linear dimensions of sheet encapsulation material resulting from applied thermal conditions
	IEC 62788-1-6 ED1	2017		Part 1-6: Encapsulants - Test methods for determining the degree of cure in Ethylene-Vinyl Acetate encapsulation for photovoltaic modules
	IEC 62788-2	2017		Part 2: Polymeric materials used for frontsheets and backsheets
	IEC/TS 62788-7-2	2017		Part 7-2: Environmental exposures - Accelerated weathering tests of polymeric materials
	SEMI PV45-0513			Test Method for the Content of Vinyl Acetate (VA) in Ethylene-Vinyl Acetate (EVA) Applied in PV Modules Using Thermal Gravimetric Analysis (TGA)
	SEMI PV75-1016			Test Method on Cell Level for Potential-Induced Degradation Susceptibility of Solar Cells and Module Encapsulation Materials
	SEMI PV72-0316			Test Method to Evaluate an Accelerated Thermo Humidity Resistance of Photovoltaic (PV) Encapsulation
Coatings	*Proposed IE 62788-8-2*		*Working item*	*Measurement procedures for materials used in photovoltaic modules - Part 8-2: Materials and coatings for the irradiant incident surface of photovoltaic modules or similar solar devices: Abrasion and environmental testing*
Packaging Materials	*IEC 62788-1-7 ED1*		*In progress*	*Measurement procedures for materials used in photovoltaic modules – Part 1-7: Test procedure for the optical durability of transparent polymeric PV packaging materials*
Polymeric Films	*IEC 62788-6-2 ED1*		*In progress*	*Measurement procedures for materials used in photovoltaic modules - Part 6-2: General tests - Moisture permeation testing with polymeric films*

7.2. Device Electrical Performance

Property and/or Characteristic	Standard	Year of Issue	Current Status	Title/Scope
Power output	IEC 60904-1 ED3	2006	Under revision	Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics
	IEC 60904-1-1	2017		Measurement of current-voltage characteristics of multi-junction photovoltaic devices
	IEC 60904-1-2		*Working item*	*Measurement of current-voltage characteristics of bi-facial photovoltaic devices*
	IEC 60904-3 ED3	2016	Under revision	Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data
	IEC 60891 ED3	2009	Under revision	Procedures for temperature and irradiance corrections to measured I-V characteristics
	ASTM E973-10			Standard Test Method for Determination of the Spectral Mismatch Parameter Between a Photovoltaic Device and a Photovoltaic Reference Cell
	IEC 62607-7-1		*In progress with TC 113*	*Nano-enabled photovoltaics measurement of the electrical performance and spectral response of tandem cells*
	ASTM E948-09			Standard Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight
	ASTM E1036-08			Standard Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells
	ASTM E2236-10			Standard Test Methods for Measurement of Electrical Performance and Spectral Response of Nonconcentrator Multijunction Photovoltaic Cells and Modules
	ASTM E2527-09			Standard Test Method for Electrical Performance of Concentrator Terrestrial Photovoltaic Modules and Systems Under Natural Sunlight
	SEMI PV56-1214			Test Method for Performance Criteria of Photovoltaic (PV) Cells and Modules Package

Property and/or Characteristic	Standard	Year of Issue	Current Status	Title/Scope
	SEMI PV57-1214			Test Method for Current-Voltage (I-V) Performance Measurement of Organic Photovoltaic (OPV) and Dye-Sensitized Solar Cell (DSSC)
Spectral responsivity	IEC 60904-7 ED3	2008	Under revision	Computation of the spectral mismatch correction for measurements of photovoltaic devices
	IEC 60904-8	2014		Measurement of spectral responsivity of a photovoltaic (PV) device
	IEC 60904-8-1	2017		Measurement of spectral responsivity of multi-junction photovoltaic (PV) devices
	ASTM E1021-06			Standard Test Method for Spectral Responsivity Measurements of Photovoltaic Devices
	SEMI PV69-1015		"current"	Test Method for Spectrum Response (SR) Measurement of Organic Photovoltaic (OPV) And Dye-Sensitized Solar Cell (DSSC)
	IEC 60891:2009			Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics
Energy rating	IEC 61853-1	2011		Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating
	IEC 61853-2	2016		Part 2: Spectral response, incidence angle and module operating temperature measurements
	IEC 61853-3		*In progress*	*Part 3: Energy Rating of PV Modules*
	IEC 61853-4		*In progress*	*Part 4: Standard reference climatic profiles*
Solar simulators	IEC 60904-9 ED2	2007	Under revision	Solar simulator performance requirements
	ASTM E927-10			Standard Specification for Solar Simulation for Terrestrial Photovoltaic Testing
	IEC 60904-9-1 ED1		*In progress*	*Collimated beam solar simulator performance requirements*

Property and/or Characteristic	Standard	Year of Issue	Current Status	Title/Scope
Linearity measurement	IEC 60904-10 ED2	2009	Under revision	Methods of linearity measurement
	ASTM E1143-05	2010		Standard Test Method for Determining the Linearity of a Photovoltaic Device Parameter with Respect To a Test Parameter
Reference device calibration	IEC 60904-2	2015		Requirements for photovoltaic reference devices
	IEC 60904-4 ED1	2009	Under revision	Reference solar devices – Procedures for establishing calibration traceability
	ASTM E1040-10			Standard Specification for Physical Characteristics of Nonconcentrator Terrestrial Photovoltaic Reference Cells
	ASTM E1362-10			Standard Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells
	ASTM E1125-10			Standard Test Method for Calibration of Primary Non-Concentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum
Equivalent Cell Temp	IEC 60904-5	2011		Photovoltaic devices - Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method
Stability/LID	IEC 60904-11 ED		Under revision	Measurement of light-induced degradation of crystalline silicon solar cells and photovoltaic modules
	IEC/TS 62876-2-1		*In progress?*	*Nanotechnology - Reliability assessment - Part 2.1: Nano-enabled photovoltaic - Stability test 113/178/NP*
	SEMI PV73-0216			Test Method for Thin-Film Silicon Photovoltaic (PV) Modules Light Soaking
Characterisation	*IEC 60904-12 ED1*		*In progress*	*Infrared thermography of PV modules*
	IEC 60904-13 ED1		*In progress*	*Electroluminesence of PV modules*

Property and/or Characteristic	Standard	Year of Issue	Current Status	Title/Scope
Energy Yield	DERLAB Testing procedure (2012)			Performance Testing of PV Modules in Outdoor Conditions

7.3. Module Design Qualification, Lifetime and Reliability

Property and/or Characteristic	Standard	Year of Issue	Current Status	Title/Scope
Design qualification and type approval	IEC 61215-1	2016		Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Requirements for testing
	IEC 61215-1-1	2016		Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules
	IEC 61215-1-2	2016		Part 1-2: Special requirements for testing of cadmium telluride (CdTe) photovoltaic (PV) modules
	IEC 61215-1-3	2016		Part 1-3: Special requirements for testing of amorphous silicon (a-Si) and microcrystalline silicon (micro c-Si) photovoltaic (PV) modules
	IEC 61215-1-4	2016		Part 1-4: Special requirements for testing of copper indium gallium selenide (CIGS) and copper indium selenide (CIS) photovoltaic (PV) modules
	IEC 61215-1-5		*in progress*	*Part 1-5: Special requirements for testing of flexible (non-glass superstrate) photovoltaic (PV) modules*
	IEC 61215-2	2016		Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures
	IEC 62941 ED1	2016	Under revision	Terrestrial photovoltaic (PV) modules - Guideline for increased confidence in PV module design qualification and type approval
	IEC TS 62915 ED1		*In progress*	*Photovoltaic (PV) modules - Retesting for type approval, design and safety qualification*
	IEC 62108 ED2	2016		Concentrator photovoltaic (CPV) modules and assemblies - Design qualification and type approval
	IEC 62787 ED1		*In progress*	*Concentrator photovoltaic (CPV) solar cells and cell-on-carrier (COC) assemblies - Reliability qualification*

Safety Qualification	IEC 61730-1 ED2	2016	Under revision	PV Module safety qualification: Part 1 Requirements for construction
	IEC 61730-2 ED2	2016	Under revision	PV Module safety qualification: Part 2 Requirements for testing
	IEC 62688	2017		Concentrator photovoltaic (CPV) module and assembly safety qualification
Crack detection	SEMI PV60-0115		"current"	Test Method for Measurement of Cracks in Photovoltaic (PV) Silicon Wafers in PV Modules by Laser Scanning
Ammonia corrosion	IEC 62716 ED1	2014		Photovoltaic (PV) modules - Ammonia corrosion testing
	SEMI PV79-0817			Test Method for Exposure Durability of Photovoltaic (PV) Cells to Acetic Acid Vapor
Thermal Cycling	*IEC 62892 ED1*		*In progress*	*Test procedure for extended thermal cycling of PV modules*
	IEC 62925	2016		Thermal cycling test for CPV modules to differentiate increased thermal fatigue durability
High temperature operation	*IEC TS 63126 ED1*		*In progress*	*Guidelines for qualifying PV modules, components and materials for operation at higher temperatures*
Tests relevant to design qualification	ASTM E1171-09			Standard Test Methods for Photovoltaic Modules in Cyclic Temperature and Humidity Environments
	ASTM E1462	2006		Standard Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules
	ASTM E1799-08			Standard Practice for Visual Inspections of Photovoltaic Modules
	ASTM E1802-07			Standard Test Methods for Wet Insulation Integrity Testing of Photovoltaic Modules
	ASTM E1830-09			Standard Test Methods for Determining Mechanical Integrity of Photovoltaic Modules
	ASTM E2047-10			Standard Test Method for Wet Insulation Integrity Testing of Photovoltaic Arrays

Snow Loads	IEC 62938 ED1		Under revision	Non-uniform snow load testing for photovoltaic (PV) modules
Surface Cut	ASTM E2685-09		Proposed update with WK20550	Standard Specification for Steel Blades Used with the Photovoltaic Module Surface Cut Test
Dynamic mechanical load	IEC/TS 62782 ED1	2016		Dynamic mechanical load testing for photovoltaic (PV) modules
Edge seal durability	*IEC 62788-5-1 ED1*		*In progress*	*Measurement procedures for materials used in photovoltaic modules - Part 5-1 Suggested test methods for use with edge seal materials*
	IEC 62788-5-2 ED1		*In progress*	*Part 5-2: Edge-Seal durability evaluation guideline*
Interfaces	*IEC TS 62788-6-3 ED1*		*In progress*	*Measurement procedures for materials used in photovoltaic modules - Part 6-3: Adhesion testing of interfaces within PV modules*
Hail tests	ASTM E1038-10			Standard Test Method for Determining Resistance of Photovoltaic Modules to Hail by Impact with Propelled Ice Balls
Hot-spot tests	ASTM E2481-08			Standard Test Method for Hot Spot Protection Testing of Photovoltaic Modules
Partial Shading	*IEC TS 63140 ED1*		*In progress*	*Photovoltaic (PV) modules – Partial shade endurance testing*
Life Testing	*Proposed ASTM WK25362*			*New Practice for Accelerated Life Testing of Photovoltaic Modules*
Potential-induced degradation	IEC TS 62804-1:	2015		Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1: Crystalline silicon
	IEC TS 62804-1-1		*In progress*	*Part 1-1: Delamination for crystalline silicon modules*
	IEC TS 62804-2		*In progress*	*Part 2: Thin-film*
Salt mist corrosion testing	IEC 61701 ED2	2011	Under revision	Salt mist corrosion testing of photovoltaic (PV) modules

	ASTM E1597-10			Standard Test Method for Saltwater Pressure Immersion and Temperature Testing of Photovoltaic Modules for Marine Environments
UV testing	SEMI PV77-0817			Guide for Calibration of Photovoltaic (PV) Module UV Test Chambers
Weathering	*ASTM WK22010*		*Proposed*	*New Guide for Testing Performances, Weathering and Aging of Photovoltaic Modules*
Bypass diode	IEC/TS 62916 Ed. 1.0	2017		Bypass diode electrostatic discharge susceptibility testing for photovoltaic modules
	IEC 62979 Ed. 1.0	2017		Photovoltaic module bypass diode thermal runaway test
Junction box safety	IEC 62790 ED1	2014	Under revision	Junction boxes for photovoltaic modules - Safety requirements and tests
Flexibility	SEMI PV78-0817			Test Method for Bending Property of Flexible Thin Film Photovoltaic (PV) Modules
Low Light Durability	SEMI PV76-0117			Test Method for Durability of Low Light Intensity Organic Photovoltaic (OPV) and Dye-Sensitized Solar Cell (DSSC)
Transportation	IEC 62759-1	2015		Photovoltaic (PV) modules - Transportation testing - Part 1: Transportation and shipping of module package units
	SEMI PV23-1011		"current"	Test Method for Mechanical Vibration of Crystalline Silicon Photovoltaic (PV) Modules in Shipping Environment
	SEMI PV44-0513		"current"	Specification for Package Protection Technology For PV Modules
	SEMI PV38-0912		"current"	Test Method for Mechanical Vibration of c-Si PV Cells in Shipping Environment
EH&S risk assessment	*IEC TS 62994 ED1*		*In progress*	*Environmental health and safety (EH&S) risk assessment of the PV module through the life cycle - General principles and definitions of terms*

7.4. Systems

Sector	Standard	Year of Issue	Current Status	Title
Terms & Definitions	IEC TS 61836	2016		Solar photovoltaic energy systems - Terms, definitions and symbols
Design requirements	IEC TS 62548	2016		Photovoltaic (PV) arrays - Design requirements
	IEC TS 62738 ED1		*In progress*	*Design guidelines and recommendations for ground-mounted photovoltaic power plants*
Commissioning, inspection, maintenance	IEC 62446-1 ED1	2016	Under revision	Grid connected photovoltaic (PV) systems - Part 1: documentation, commissioning tests and inspection
	IEC 62446-2		*In progress*	*Part 2: Maintenance of PV systems*
	IEC/TS 62446-3	2017		Part 3: Outdoor infrared thermography of photovoltaic modules and plants
	IEC TS 63049	2017		Terrestrial photovoltaic (PV) systems - Guidelines for effective quality assurance in PV systems installation, operation and maintenance
Electrical performance	IEC 61724-1	2017		Photovoltaic system performance - Part 1: Monitoring
	IEC 61724-2	2016		Part 2: Capacity evaluation method
	IEC 61724-3	2016		Part 3: Energy evaluation method
	IEC 61829 ED2	2015		Photovoltaic (PV) array - On-site measurement of current-voltage characteristics
	IEC 61725	1997		Analytical expression for daily solar profiles
	ASTM WK22009		*Proposed*	*New Test Method for Reporting Photovoltaic Non-Concentrator System Performance*
	IEC 62670-1	2013		Photovoltaic concentrators (CPV) - Performance testing - Part 1: Standard conditions
	IEC 62670-2	*2015*		*Part 2: Energy measurement*
	IEC 62670-3	*2017*		*Part 3: Performance measurements and power rating*

Sector	Standard	Year of Issue	Current Status	Title
Availability	*IEC TS 63019 ED1*		*In progress*	*Information model for availability of photovoltaic (PV) power systems*
Land Use	*IEC TR 63149 ED1*		*In progress*	*Mathematic models and calculation examples for land usage of PV farms*
Earthing	*IEC 63112 ED1*		*In progress*	*Safety, functionality and classification of Photovoltaic Earth Fault Protection equipment*
Utility interface	IEC 61727	2004		Photovoltaic (PV) systems - Characteristics of the utility interface
	SEMI PV2-0709E			Guide for PV Equipment Communication Interfaces (PVECI)
Power Conversion	IEC 62920	2017		EMC requirements and test methods for power conversion equipment applying to photovoltaic power generating systems
	IEC 62093 ED1	2005	Under revision	Power conversion equipment for PV systems: design qualification testing
	IEC 62109-1	2010		Safety of power converters for use in photovoltaic power systems - Part 1: General requirements
	IEC 62109-2	2011		Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters
	IEC 62109-3		*In progress*	*Safety of power converters for use in photovoltaic power systems - Part 3: Particular requirements for electronic devices in combination with photovoltaic elements*
	IEC 61683 ED1	1999	Under revision	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency
	IEC TS 63106-1		*in progress*	*Basic requirements for simulator used for testing of photovoltaic power conversion equipment - Part 1: AC power simulator*
	IEC TS 63106-2		*in progress*	*Part 2: DC power simulator*

Sector	Standard	Year of Issue	Current Status	Title
	IEC TS 63156 ED1		Under revision	Power conditioners - Energy evaluation method
	IEC TS 63157 ED1		Under revision	Guidelines for effective quality assurance of power conversion equipment for photovoltaic systems
Arc detection	*IEC 63027 ED1*		*In progress*	*DC arc detection and interruption in photovoltaic power systems*
DC-connectors	IEC 62852 ED1	2014	Under revision	Connectors for DC-application in photovoltaic systems - Safety requirements and tests
Inverters	IEC 62894	2016		Photovoltaic inverters - Data sheet and name plate
	IEC TS 62910	2015		Utility-interconnected photovoltaic inverters - Test procedure for low voltage ride-through measurements
	IEC 62891 ED1		*In progress*	*Overall efficiency of grid connected photovoltaic inverters*
	IEC 62116	2014		Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures
	IEC TR 61850-90-7	2013		Communication networks and systems for power utility automation - Part 90-7: Object models for power converters in distributed energy resources (DER) systems
Battery controllers	IEC 62509 ED1	*2010*		Battery charge controllers for photovoltaic systems - Performance and functioning
Trackers	IEC TS 62727	2012		Photovoltaic systems - Specification for solar trackers
	IEC 62817	2017		Photovoltaic systems - Design qualification of solar trackers
	IEC 63104 ED1		*In progress*	*Solar trackers - Safety requirements*

7.5. Integrated Applications

Sector	Standard	Year of Issue	Current Status	Title
Building Integrated	ISO 52000-1	2017		Energy performance of buildings -- Overarching EPB assessment -- Part 1: General framework and procedures
	EN-15316-4-3	2017		EPB - Method for calculation of system energy requirements and system efficiencies - Part 4-3: Heat generation systems, thermal solar and photovoltaic systems
	IEC 62980 ED1		*In progress*	*Photovoltaic modules for building curtain wall applications*
	EN 50583-1	2016		Photovoltaics in buildings - Part 1: BIPV modules
	EN 50583-2	2016		Photovoltaics in buildings - Part 2: BIPV systems
	IEC 63092-1		*Due 2019*	*BIPV modules*
	IEC 63092-2		*Due 2019*	*BIPV systems*
	IEC 60364-7-712	2017		Low voltage electrical installations - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems
Rooftop	CENELEC - CLC/TR 50670	2016		External fire exposure to roofs in combination with photovoltaic (PV) arrays - test method(s)
	ASTM WK21327		*Proposed*	*New Practice for the Installation of Roof Mounted Photovoltaic Arrays*
PV pumping systems	IEC 62253 ED1	2011		Photovoltaic pumping systems - Design qualification and performance measurements
Consumer products	*IEC 63163 ED1*		*In progress*	*Terrestrial photovoltaic (PV) modules for consumer products - Design qualification and type approval*
Cars	EU Implementing Decision 2016/1926	2016		On the approval of the battery-charging photovoltaic roof as an innovative technology for reducing CO2 emissions from passenger cars pursuant to Regulation (EC) No 443/2009
Standalone systems	IEC 62124 ED1	2004		Photovoltaic (PV) stand alone systems - Design verification

Sector	Standard	Year of Issue	Current Status	Title
Systems for rural electrification	IEC/TS 62257-7-1 ED3	2015	Under revision	Recommendations for renewable energy and hybrid systems for rural electrification - Part 1: General introduction to IEC 62257 series and rural electrification
	IEC/TS 62257-7-2 ED2	2015	Under revision	Part 2: From requirements to a range of electrification systems
	IEC/TS 62257-7-3 ED2	2015	Under revision	Part 3: Project development and management
	IEC/TS 62257-7-3 ED1	2015	Under revision	Part 4: System selection and design
	IEC TS 62257-6:2015	2015		Part 6: Acceptance, operation, maintenance and replacement
	IEC TS 62257-7:2017	2017		Part 7: Generators
	IEC TS 62257-7-1	2010		Part 7-1: Generators - Photovoltaic generators
	IEC TS 62257-7-3	2008		Part 7-3: Generator set - Selection of generator sets for rural electrification systems
	IEC/TS 62257-8-1 ED1	2007	Under revision	Part 8-1: Selection of batteries and battery management systems for stand-alone electrification systems - Specific case of automotive flooded lead-acid batteries available in developing countries
	IEC/TS 62257-9-1	2016		Part 9-1: Micropower systems
	IEC/TS 62257-9-2	2016		Part 9-2: Microgrids
	IEC/TS 62257-9-3	2016		Part 9-3: Integrated system - User interface
	IEC/TS 62257-9-4	2016		Part 9-4: Integrated system - User installation
	IEC/TS 62257-9-5 ED3	2016	Under revision	Part 9-5: Integrated systems - Selection of stand-alone lighting kits for rural electrification
	IEC/TS 62257-9-6 ED1	2008	Under revision	Part 9-6: Integrated system - Selection of Photovoltaic Individual Electrification Systems
	IEC/TS 62257-9-7 ED1		*Proposal*	*Part 9-7: Integrated system - Selection of Inverters*
	IEC TS 62257-12-1	2015		Part 12-1: Selection of lamps and lighting appliances for off-grid electricity systems

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