# CALL FOR PAPERS

## Technical Program


## 7th WCPEC:
## 45th IEEE PVSC
## 34th EU PVSEC
## 28th PVSEC

**June 10-15, 2018**
**Hilton Waikoloa Village, HI USA**

**Late News Abstract deadline: April 2, 2018**

# Call for Papers

As a testimony to WCPEC's premier international conference dimension and as a part of our regular call for paper we received over 1200 submissions from more than 60 countries. The Program Committee has already selected and scheduled more than 1100 presentations across 110 Keynote, Plenary, Oral and Poster sessions.

Now and on behalf of the Program Committee, it is our pleasure to invite you to submit an abstract on your post-regular deadline achievements in photovoltaics to the 7th WCPEC and to seize a unique opportunity to share and discuss these developments in a timely and influential forum.

This year, the Program Committee has set aside few openings to make the option for an oral presentation available to authors of exceptional breakthroughs.

To have your paper considered for a "Late News" presentation at the 7th WCPEC, please submit a 3-page evaluation abstract, and a short abstract of no more than 300 words in length for display on the WCPEC website. Evaluation abstracts are expected to be detailed enough to allow a competent technical review. Please follow the suggested format, a template has been provided at the conference website for your convenience. Abstract submission is via the 7th WCPEC website at "http://www.wcpec7.org" by using your user name and password. Please carefully follow the instructions provided to upload your abstract successfully.

**We are also continuing the option of offering a**uthors who submit particularly high quality Late News evaluation abstracts an opportunity to directly submit a manuscript to the IEEE Journal of Photovoltaics. This path allows authors to enjoy both the PVSC conference experience as well as publishing their work in a high impact journal.

**The deadline for electronic submission of the Late News abstracts is April 2nd, 2018** at midnight Pacific Standard Time (UTC - 8 hours). Late News contributing authors will be notified of the acceptance status of their papers after April 16th, 2018. For visa applications, an invitation letter can be issued any time after you register for the conference. We will also ask authors to confirm that they will be able to present their work at the conference and upload their manuscript by the due date of **May 21st, 2018** for publication in the conference proceedings.

On behalf of the Technical Program Committee, we look forward to welcoming and meeting with you at the 7th WCPEC on the beautiful island of Hawaii.

***Sylvain Marsillac, Yoshio Ohshita & Wim Sinke***
***Technical Program Chairs***
***2018* 7th WCPEC**

## Area 1: Fundamentals and New Concepts for Future Technologies

Chair: Karin Hinzer *(U. Ottawa, Canada)*

Co-Chairs: Peichen Yu *(National Chiao Tung University, Taiwan)*
Laurent Lombez *(IRDEP, France)*

**Area Description**

Paradigm shifts in solar cell technology are invariably preceded by breakthroughs arising from basic scientific research. In recent years, there have been a number of exciting results in the fundamental arena, including the demonstration of two-photon absorption processes in nanostructured solar cell devices, and sophisticated optical management designs resulting in world record single-junction and dual-junction cell efficiencies. Area 1 comprises fundamental research and novel device concepts that will provide a platform for the development of future photovoltaic technologies. Papers are sought describing research in basic physical, chemical and optical phenomena, in addition to studies of new materials and innovative device designs. Subjects of particular interest include, but are not limited to, nanostructures, hybrid tandem devices, advanced optical management approaches, new materials and synthesis processes, and unconventional conversion mechanisms.

### Sub-Area 1.1: Fundamental Conversion Mechanisms

*Sub-Area Chair: Jeremy Munday (University of Maryland, USA)*

Sub-Area 1.1 captures both experimental and theoretical work exploring new paradigms for solar energy conversion. Papers submitted to this Sub-area would explore the fundamental physics or present initial experimental demonstrations related to novel energy conversion mechanisms. Papers on modeling and simulation of new device architectures to enable these conversion mechanisms are also encouraged. Areas of interest include, but are not limited to, non-conventional PV conversion processes based on quantum confined or nanostructured systems, engineered band alignments, intermediate band concepts, multiple exciton generation (MEG), thermophotonics or hot-carrier effects. Also of interest are concepts and demonstration of new materials and material science related to energy conversion. Finally, cross cutting science approaches involving novel physics, innovative device structures, and modeling and simulation are solicited.

### Sub-Area 1.2: Quantum-well, Wire, and Dot-Architectured Devices

*Sub-Area Chair: Ian Sellers (University of Oklahoma, USA)*

In recent years significant advancements in optoelectronics have been achieved via the implementation of low-dimensional systems. Sub-area 1.2 focuses on using quantum-engineered structures to improve and facilitate the performance of photovoltaic devices. The use of quantum-dots, wells, and wires have the potential to increase the efficiency of solar cells in excess of 50% when used in novel third generation technologies and multi-junction solar cells. To continue recent momentum in these fields, papers are sought on both the theoretical and experimental progress in the development of quantum-engineered materials and devices. Submissions including novel designs, new material compositions, implementation of new uses of quantum confinement, and the exploitation of varying

dimensionality of confinement are encouraged. Ideal submissions will range from studies of fundamental physics to examples of working devices.

**Sub-Area 1.3: Advanced Light Management and Spectral Shaping**
*Sub-Area Chair: Ulrich Paetzold (Karlsruhe Institute of Technology, Germany)*

In order to achieve high power conversion efficiency, a solar cell must effectively utilize most of the incoming photons. This process involves the efficient coupling of the incident light into the solar cell with minimum loss, and effective use of the energy imparted by each photon. This Sub-area will focus on novel concepts, including advanced anti-reflection coatings, spectrum splitting, textured light trapping surfaces (front and/or rear surface), luminescent (fluorescence) and nano-scale concentrator systems, and advanced photonic and plasmonic structures. With respect to plasmonics, both light trapping and hot carrier effects will be considered. In addition, ways to modify the spectrum of the incident sunlight using techniques such as up or down conversion either in planar layers or in waveguide structures will be considered. Papers submitted to this Sub-area should address one or more of these themes and may be theoretical or experimental in nature.

**Sub-Area 1.4: Novel Material Systems**
*Sub-Area Chair: Louise Hirst (Naval Research Laboratory, USA)*

Sub-Area 1.4 covers progress on the development of novel materials and processing techniques for improving the performance, functionality, reliability, and scalability of PV devices. Such materials, combinations, and processes may find application in single-crystalline, thin film, multijunction, and nanostructured PV devices or may enable an entirely new device class on their own. Papers are sought that describe theoretical and/or experimental development of materials displaying novel properties, including but not limited to semiconductors, substrates, coatings, barriers, transparent conductive oxides (TCOs), pseudomorphic and metamorphic photovoltaic materials. Developments in the field of graphene and carbon nanotubes are of interest in this Sub-area. Advances in growth, synthesis, deposition, doping and passivation schemes as well as new architectures that have the potential to lower material quality constraints are also solicited.

*(*) Note that if your work focuses mostly on Hybrid Tandem/Multijunction solar cells, you should submit to Area 3.3*

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# Area 2: Chalcogenide Thin Film Solar Cells

Chair: Nicolas Barreau (Univ. Nantes, France)

Co-Chairs: Takeaki Sakurai (Univ. Tsukuba, Japan)
Chris Ferekides (Univ. South Florida, USA)

## Area description

In the past 5 years, thin film chalcogenide solar cells based on CIGSe, CdTe have achieved remarkable progress in terms of record conversion efficiencies >22% and manufacturing at the multi gigawatts-per-year scale. These exciting developments have been enabled by the decades of work by the worldwide community of dedicated research, development, and manufacturing professionals working on their science and technology.

Area 2 brings this community together yearly to present and discuss contributions on solar cells based on CdTe, $Cu(In,Ga)(S,Se)_2$ (CIGSSe), $Cu2ZnSn(S,Se)_4$ (CZTSSe), and related materials. The aims of Area 2 are to provide a platform for presenting recent and on-going research leading to improved understanding of materials and devices, exploring new directions for more efficient production, and narrowing the gap between champion cell and module efficiencies. Topics typically range from insights into basic materials science, to analysis of device properties and new device structures, to discussions of the progress in deposition methods and growth control, and to long term performance and reliability. We look forward to an exciting, cutting-edge conference that helps advance the science and technology of these fascinating and technologically-important solar cells.

### Sub-Area 2.1: Absorber Preparation and Material Properties

*Sub-Area Chairs:* *Yukiko Kamikawa (AIST, Japan)*
*Charlotte Platzer-Björkman (Uppsala University, Sweden)*

Because minority carrier lifetime and collection in the absorber dominates efficiency in chalcogenide thin film devices, the preparation and properties of the absorber layer are of paramount importance. Sub-area 2.1 addresses progress in understanding thin film formation and the influence of processing on basic material properties and device performance. Examples of relevant topics include both experimental and theoretical aspects of: morphology, phase coexistence, microstructure, optoelectronic and transport properties, influence of substrates, compositional gradients and homogeneity, effects of material purity and contaminants, interrelation of properties and cell and module fabrication processes, in-situ, ex-situ and in-line methods of characterization, and impacts on short- and long-term performance.

### Sub-Area 2.2: Contacts, Windows, Buffers, Substrates and Superstrates, Monolithic Integration, and Interfaces

*Sub-Area Chairs:* *Takashi Minemoto (Ritsumeikan University, Japan)*
*Christian Kaufmann (HZB, Germany)*

The processing and properties of all of the layers in the thin film device stack as well as their integration into monolithically-integrated modules ultimately determine the cell and

module performance. Sub-area 2.2 focuses on the functions, effects and properties of substrates/superstrates, contacts, buffer and window layers, and interfaces. Submissions describing advances in understanding these aspects and their effects on short-and long-term performance are welcome. Papers on progress in the cross-cutting areas of transparent conductors, moisture barriers, new or improved substrates, established and novel methods of cell scribing and interconnection in modules, and novel topics not listed are encouraged.

**Sub-Area 2.3: Cell and Module Characterization, Analysis, Theory, and Modeling**
*Sub-Area Chairs:* *Su-Huai Wei (CSRC, China)*
*Pawel Zabierowski (WUT, Poland)*

Continued progress in chalcogenide photovoltaics relies on continuing to gain insight into the origins of efficiency loss and concepts for overcoming them. Whereas Sub-areas 2.1 and 2.2 focus on the physical properties and processing of the layers making up cells and modules, Sub-area 2.3 addresses their net effects at the device and module level through measurement, analysis, theory, and modeling. These aspects enable feedback to continue improving cells and modules. Contributions are solicited in the areas of novel and established characterization methods, device analysis that yields insight into internal operation, one-, two- and three-dimensional modeling to understand current devices and guide progress, characterization of defects and recombination, and novel related topics not listed.

**Sub-Area 2.4: Progress in Manufacturing and Deployment**
*Sub-Area Chairs:* *Shogo Ishizuka (AIST, Japan)*
*Mirjam Theelen (TNO/Solliance, The Netherlands)*

As installed capacity of CdTe and CIGSSe modules is approaching 15 gigawatts and achieving cost-parity with other module technologies and fossil fuels, the field of chalcogenide thin film photovoltaics is rapidly transitioning from a focus solely on R&D into large-scale manufacturing and deployment. Sub-area 2.4 solicits contributions addressing module manufacturing and field deployment. Emphasis is placed on paths to continue improving long-term field performance and reliability while continuing to enhance cost and reliability (in addition to performance) as key drivers for developing a viable, thin-film module manufacturing capability. We encourage the community to share their experience and knowledge in areas focused on reducing the cost/watt of PV modules including higher throughput/yield and more energy and cost-effective processing, improvements in thin-film uniformity, improved cell integration and module architectures, important quality control metrology/diagnostics and information management applied during semiconductor deposition, integration, packaging, and reliability testing. Papers are also sought in the area of cell and module reliability, in particular field and laboratory-test procedures and results, qualification testing, degradation mechanisms, and transient behavior.

*(*) Note that if your work focuses mostly on Hybrid Tandem/Multijunction solar cells, you should submit to Area 3.3*

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## Area 3: Multijunction and Concentrator Technologies

Area Chair: Tyler Grassman (The Ohio State University, USA)

Co-Chairs: Kenji Araki (Toyota Technological Institute, Japan)
Frank Dimroth (Fraunhofer Institute for Solar Energy Systems, Germany)

**Area Description**
III-V multijunction solar cells, at least within the last decade or so, have been the basis for high-performance terrestrial concentrator photovoltaics (CPV) technologies. However, the multijunction architecture is also the only proven approach for providing efficiencies beyond the single-junction Shockley-Queisser limit. Therefore, Area 3 addresses not only III-V solar cells and CPV technologies, but also integrates a wide range of topics covering the science, engineering, performance, cost, and reliability of multijunction devices and concentrator applications, in general.

Sub-Area 3.1 focuses on the research and development of "traditional" III-V based single and multijunction solar cells. Given the relatively high costs of III-V materials and devices at present, Sub-Area 3.2 focuses on the development of low-cost approaches for III-V photovoltaics. Additionally, work in the area of high-performance multijunction cells not tied entirely to the III-V regime is rapidly growing. Therefore, Sub-Area 3.3 encompasses a broader scope regarding the development of "hybrid" multijunction solar cells, wherein devices are made up of multiple classes of photovoltaic materials. Finally, Sub-Area 3.4 integrates the range of topics related to terrestrial CPV demonstrators, modules, and systems, including all levels of concentration, as well as hybrid modules capturing diffuse radiation, capturing and converting heat energy, and/or generating solar hydrogen.

### Sub-Area 3.1: III-V Single and Multijunction Solar Cells

*Sub-Area Chair: Ryan France (National Renewable Energy Laboratory, USA)*
*Ivan Garcia (Universidad Politécnica de Madrid, Spain)*

This Sub-Area seeks to address all relevant aspects of the research and development of III-V single and multijunction solar cells for terrestrial applications. Topics of interest include (but are not necessarily limited to): epitaxial growth, materials design and development, solar cell architectures, single and multi-junction devices, nano-wire devices, cell-level theoretical modeling, cell-level photon management, wafer bonding, device processing, new manufacturing technologies, material and cell characterization, and III-V cell reliability.

### Sub-Area 3.2: Low Cost III-V Materials and Solar Cells

*Sub-Area Chair: Minjoo L. Lee (University of Illinois, USA)*
*Takeyoshi Sugaya (National Institute of Advanced Industrial Science and Technology, Japan)*

This Sub-Area integrates the "Low Cost III-V" Joint Area of previous years. Topics of interest here are broadly defined as technologies and approaches related to the achievement of low-cost III-V materials and solar cells. Papers are solicited on the growth of crystalline and polycrystalline III-V materials on alternative substrates where the

substrate is not an active photovoltaic component (i.e. excluding typical single-crystal materials like Ge or III-Vs). Papers are also sought on low-cost III-V growth and deposition techniques, such as HVPE and ultra-high-rate OMVPE/MOCVD. Papers on epilayer lift-off and substrate re-use are also sought. Work on the characterization of associated materials and devices is encouraged.

### Sub-Area 3.3: Hybrid Tandem/Multijunction Solar Cells

*Sub-Area Chair: Adele Tamboli (National Renewable Energy Laboratory, USA)*
*Ed Crossland (Oxford PV, UK)*

This Sub-Area integrates the "Hybrid Tandem" Joint Area of previous years. This wide-reaching Sub-Area solicits papers regarding materials, structures, and devices based on combinations of multiple different materials classes—III-Vs, Si, chalcogenides/thin-films, organics, perovskites, etc.—toward the production and characterization of "hybrid" multijunction solar cells. The full range of integration methodologies are of interest, including but not limited to monolithic epitaxy and deposition, wafer bonding, and mechanical stacking. Characterization of these materials, structures, and devices, from the atomic scale to the device level (and beyond), as related to their hybrid nature, is also of interest. Papers on the theory and modeling of such devices are welcome, as is work related to new module and system architectures optimized for such hybrid cells.

### Sub-Area 3.4: CPV Modules and Systems

*Sub-Area Chair: Mathieu Baudrit (CEA-INES, France)*
*Kensuke Nishioka (Miyazaki University, Japan)*

This Sub-Area seeks to address all relevant aspects of the research and development of concentrated photovoltaics modules and systems. Module-related topics of interest include (but are not necessarily limited to): primary optics, acceptance angle studies, performance modeling, module design, module-level environmental mitigation (heat, humidity, etc.), module reliability, manufacturing advances and concerns, and module-level integrated storage. System-related topics of interest include (but are not necessarily limited to): concentrator system design, concentrator assemblies, trackers, system-level characterization, soiling, system reliability, environmental influences, maintenance, energy yield and performance modeling/prediction, system-level integrated storage, life-cycle analysis, and economics/financing/markets. All levels of optical concentration are of interest.

## Area 4: Silicon Photovoltaic Materials and Devices

Chair: Mariana Bertoni (ASU, USA)

Co-Chairs: Giso Hahn (U. Konstanz, Germany),
Ziv Hameiri (UNSW, Australia)

### Area Description

Area 4 invites contributions reporting on all aspects of silicon technology, including silicon material, standard crystalline silicon wafer-based technology, thin film silicon and silicon-based tandem structures, from fundamentals and device physics to processing and module integration. All contributions covering crystalline, or thin-film, silicon technologies and devices are welcome, including new silicon purification, feedstock and wafer production technologies (Sub-area 4.1); all standard pn-junction based crystalline silicon devices and processes such as Al-BSF, PERC, PERT, IBC, bifacial (Sub-area 4.2); surface passivation, optical coating and light management (Sub-area 4.3); passivated contacts, carrier selective contacts, heterojunction (HJ) structure and contacts (Sub-area 4.4); metallization, contact formation and module integration (Sub-area 4.5); modeling, numerical simulation and device physics (Sub-area 4.6); thin-film silicon material and devices (Sub-area 4.7).

### Sub-Area 4.1: Silicon Material, Feedstock and Wafers: Technology and Analysis

*Sub-Area Chair:* *Martin Schubert (Fraunhofer ISE)*
*Gianluca Coletti (ECN)*

This Sub-area covers the first part of the value chain from silicon purification and feedstock production through crystallization and wafering, including high-performance multi-crystalline silicon wafers, kerf-less slicing technologies, alternative methods to produce silicon wafers such as direct wafer or wafers formed by epitaxy. Additionally, abstracts addressing the mechanical and electrical characteristics of the resulting wafers, including material quality, defects (e.g. carrier induced degradation) and defect engineering steps (e.g. gettering, hydrogenation, regeneration) of the silicon material are welcome.

### Sub-Area 4.2: Homojunction Devices & Technologies

*Sub-Area Chair:* *David Fenning (UCSD)*
*Qi Wang (Jinko Solar)*

This Sub-area covers all the different standard solar cell structures based on pn-junction doping technologies, including for example papers reporting on advances in Al-BSF solar cells, PERC, PERT, IBC, MWT, bifacial cells, either p-type or n-type. Topics related to the junction formation, doping technologies (laser doping, ion implantation), film deposition methods, new designs and new process technologies are all welcome in this Sub-area.

### Sub-Area 4.3: Surface Passivation, Optical Coating and Light Management

*Sub-Area Chair:* *Zachary Holman (ASU)*
*Bram Hoex (UNSW)*

With increasing quality of the silicon material, the surfaces of the solar cells are becoming more and more important. Optical coating and surface texturing are critical for light

management as well as for surface recombination parameters. This Sub-area welcomes abstracts covering all aspects of surface passivation like dielectric layers, organic/inorganic interfaces, surface cleaning and passivation mechanisms. Another important aspect related to the surfaces of silicon solar cells is improved light management. This Sub-area also welcomes submissions addressing enhanced photon absorption by classical, diffractive and plasmonic mechanisms, as well as black-silicon technologies.

**Sub-Area 4.4: Passivated Contacts, Carrier Selective Contacts and Hetero-Junction Structures**

*Sub-Area Chair:* *Christophe Ballif (EPFL)*
*Yimao Wan (ANU)*

This Sub-area welcomes all abstracts related to solar cells fabricated with heterojunction or passivated contacts. Papers reporting on the formation and characterization of all passivated contacts and carrier-selective contacts, including hetero-junction contacts and Metal-Insulator-Semiconductor (MIS) contacts, characterization of tunnel current, trade-off between surface recombination and contact resistance, as well as large volume processing issues should be submitted to this Sub-area.

**Sub-Area 4.5: Metallization, Contact Formation and Module Integration**

*Sub-Area Chair:* *Alison Lennon (UNSW)*
*Radovan Kopecek (ISC)*

The final step of cell processing is the formation of contacts. This Sub-area welcomes manuscripts covering all current and novel techniques for contact formation, including but not limited to printed metallization, plating, evaporation, dispensing or other transfer techniques, conductive adhesives, soldering, laser and thermal alloying of metals, and transparent electrodes. The contacts are also the interface to the subsequent module integration. Therefore topics like mechanical adhesion, multi-wire technologies and the interconnection of advanced cell structures like back-contact cells are also addressed in this Sub-area.

**Sub-Area 4.6: Device Physics, Simulation and Power Loss Analysis**

*Sub-Area Chair:* *Pietro Altermatt (Trina Solar)*
*Keith McIntosh (PV Lighthouse)*

The development of advanced solar cell architectures requires an in-depth understanding of the underlying device physics. This Sub-area covers aspects like device physics, modeling, analysis of novel cell concepts, power loss analysis of solar cells and numerical simulation.

**Sub-Area 4.7: Thin-Film Silicon Material Growth and Devices**

*Sub-Area Chair:* *Takuya Matsui (AIST)*
*Olindo Isabella (TU Delft)*

Thin-film silicon covers a class of materials that ranges from amorphous silicon and its group-IV alloys, over nano- and microcrystalline silicon, silicon-oxides and -carbides, to thin-films of crystalline silicon. Research and development in this active area addresses many solar cell devices, as well as fundamental concepts of material quality, recent insight into

light-induced degradation in thin-film silicon material, passivation of internal interfaces and heterojunctions.

*(*) Note that if your work focuses mostly on Hybrid Tandem/Multijunction solar cells, you should submit to Area 3.3*

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## Area 5: Characterization Methods

Chair: Gerald Siefer (Fraunhofer ISE, Germany)

Co-Chairs: Harvey Guthrey (NREL, USA)
Thorsten Trupke (UNSW, Australia)

**Area Description**

It is impossible to understand innovation in science without the support of measurements and characterization. Measurements are needed at any level of R&D and production - from the investigation of the operating principles of solar cells over to the development of standards for the performance of installed PV systems. Understanding the relations between structure, physical properties, and the resulting PV performance is an exemplary problem in materials science and engineering. Reliable and precise determination of the efficiency and thus power of solar cells and PV modules is crucial for the successful widespread deployment of photovoltaics.
Area 5 is intended for papers with focus on the latest developments in the characterization of photovoltaics. However, joint sessions with other topic areas are foreseen for papers with focus on characterization but applications to one specific technology.

### Sub-Area 5.1: New Instruments and Methods, In-situ Monitoring and Process Control

*Sub-Area Chair: Michael Gostein (Atonometrics , USA)*

In the last decade improvements in methods and instrumentation in the field of the characterization of PV have been extraordinary. This subarea targets on novel characterization methods and characterization equipment. This involves both – laboratory based characterization as well as in-line high throughput characterization. This includes methods and equipment for the in-situ monitoring of the deposition or growth of PV material.

### Sub-Area 5.2: Optical and Electrical Characterization Techniques for PV

*Sub-Area Chair*: *Sascha Sadewasser (INL, Portugal)*

Papers describing any aspect of the optical and/or electrical response of PV materials and full devices are welcome in this Sub-Area, including the application of scanning probe and scanning electron microscopies, and other imaging methods for the analysis of defects, surface passivation, carrier recombination, light trapping effects, etc., on the overall device performance. For this Sub-Area, papers focusing on the technique rather than the material aspects are strongly encouraged.

### Sub-Area 5.3: Characterization of Polycrystalline or Amorphous Thin Film PV

*Sub-Area Chair: Mohit Tuteja (University of Maryland, USA)*

This Sub-Area will focus on the characterization of polycrystalline or amorphous thin film PV, with emphasis on their structure, properties, and how these relate to processing and performance, with a focus on the materials. The discussion of both well-established (such as chalcogenides) and emerging materials (such as earth abundant materials) is equally welcome.

**Sub-Area 5.4: Characterization of Crystalline PV Materials and Devices**
*Sub-Area Chair: Martin Schubert (Fraunhofer ISE, Germany)*

Papers focusing on characterization and characterization methods for crystalline Silicon and III-V materials and devices should be submitted here. Optical, electronic, and structural characterization as it applies to optical and/or electronic properties, is of interest. Characterization of large grain multi- and poly-crystalline materials and devices is also appropriate for this Sub-area.

**Sub-Area 5.5: Characterization of Perovskite Solar Cells and Materials**
*Sub-Area Chair: Marina Leite (University of Maryland, USA)*

The rapid progress of perovskite solar cells in the last years resulted in high efficiency devices; however, we are far from achieving complete understanding of why the material achieves near-perfect optoelectronic properties as initially grown, but is often unable to retain those near-perfect properties when exposed to light or atmospheres with oxygen/water. This joint Sub-Area encourages the submission of papers discussing the characterization and analysis of perovskite solar cells, including the development of measurement techniques to probe its optoelectronic properties and their relationship to chemical structure. Characterization techniques that elucidate the degradation mechanisms are of particular interest. The understanding of what makes perovskites so easily achieve near-perfect properties as well as the chemical composition changes and how they affect the optoelectronic response of the devices is required for the rational design of stable perovskite solar cells.

**Sub-Area 5.6: Performance Testing and Standards**
*Sub-Area Chair: Dean Levi (NREL, USA)*

A key component of characterization, especially of cells, modules and systems, is testing of the performance and efficiency. Papers related to such characterization methods are welcome in this sub-area. In addition, this Sub-Area is intended for submissions related to standardization approaches to characterization. For example, standards for light flux measurement, calibration methods for simulators, testing temperatures, and other fundamental parameters of characterizations that also might potentially be incorporated into future standards could be submitted here.

**Sub-Area 5.7: Characterization Techniques for PV Modules and Systems**
*Sub-Area Chair: Yoshihiro Hishikawa (AIST, Japan)*

Papers focusing on characterization of complete modules and systems where the nature of the device is dominated by the ensemble of microscopic behaviors distributed throughout a large area rather than the understanding of individual microscopic behaviors should be submitted in this Sub-Area. For example, papers in this Sub-area could focus on methods such as LBIC or electroluminescence specifically as applied to understanding module performance rather than the same methods applied to small areas of device. Other examples of papers relevant to this area include adaptation of existing methods to characterize

modules from emerging technologies such as perovskites or addressing the characterization of degradation mechanisms of modules or systems of those materials.

## Area 6: Perovskite and Organic Solar Cells

Chair: Nicole Kotulak (US Naval Research Laboratory, USA)

Co-Chairs: Shuzi Hayase (Kyutech, Japan)
Sam Stranks (Cambridge, UK)

### Area Description

This focus area covers the latest scientific and technical progress of perovskite, organic, and hybrid solar cells. These photovoltaic (PV) technologies have shown incredible recent progress and are being actively investigated within the research community. Solution processed perovskite solar cell efficiencies have rocketed to >22% with just a few years of research. This kind of solar cell is a prime example of interdisciplinary research drawing together expertise from chemistry, materials science, physics, and engineering. Based on abundant materials and scalable coating technologies, these emerging PV technologies show potential for low-cost, lightweight, and flexible solar power generation and will soon have to prove their viability in the market with an acceptable combination of efficiency, stability, and in some cases environmental benignity at scale. Many of the underlying physical processes are still being explored and this helps pave the path forward for uncovering the true potential of these emerging technologies. The goal of this focus area is to address issues ranging from fundamental science to technological advances and challenges associated with manufacturable scaling in the highly interdisciplinary Sub-areas outlined below. Furthermore, Area 6 will offer a unique possibility to strengthen interactions and integration between researchers from these emerging PV technologies and the greater PV community, something everyone will benefit from.

### Sub-Area 6.1: Perovskite Solar Cells

*Sub-Area Chair: Giles Eperon (University of Washington, USA)*

Sub-Area 6.1 covers the latest developments in organic-inorganic hybrid and fully inorganic halide perovskite based solar cells. The rapid progress in this material class for solar cells has come as a surprise to many; power conversion efficiencies of perovskite solar cells are already comparable to those of established thin film technologies. The materials are highly tunable, making them attractive for a range of applications including building-integrated PV and tandem solar cells. This Sub-area focuses especially on the tunability offered by substitution of elements, which may enable better performance, new device architectures, advances in stability, and novel processing steps. We invite contributions from the broad range of topics relating to halide perovskite-based PV.

### Sub-Area 6.2: Organic and Hybrid Solar Cells

*Sub-Area Chair: Anvar Zakhidov (Texas State University, USA)*

Sub-Area 6.2 focuses on organic solar cells and hybrid materials systems. Concurrent efforts in novel materials and device architectures have led to numerous reports of efficiencies above 10%. A better understanding of how the molecular structure influences the optoelectronic properties of solar cells is often considered as key for the targeted synthesis of high performance absorber molecules. Additionally, optimal device design requires insight into the processes of free charge carrier generation, recombination and extraction as

well as modeling of opto-electronic device properties. Great strides in device stability have also been demonstrated and guidelines for designing stable absorbers and contacts are being sought.
Finally, the processing science of organic solar cells, with emphasis on scalable deposition methods, is important for the development of robust manufacturing methodologies. Therefore, this Sub-area welcomes a broad range of submissions from first principles design and synthesis of new donor and acceptor materials, methods of how to influence and characterize their microstructure in thin films to device optimization, stability and scalability.

**Sub-Area 6.3: Device Stability**
*Sub-Area Chair:*

PV technologies of Sub-areas 6.1-6.2 have shown very encouraging efficiencies and accelerated lifetime testing shows the potential of lifetimes of more than 10 years. However, this is still far away from the targeted 25 years that conventional silicon PV guarantees. On the one hand, the understanding of the various degradation pathways has to be improved. On the other hand, a major challenge is reliably predicting solar cell and module operating lifetimes for the constantly changing materials sets and stack designs being investigated. Sub-Area 6.3 invites contributions on operating lifetime studies and concepts to improve the device stability, from more stable materials to high quality encapsulation.

**Sub-Area 6.4: Scale-Up and Applications**
*Sub-Area Chair: Yasuhiro Shirai (National Institute for Materials Science, Japan)*

It is clear that on the way to large-scale production, correspondingly large-scale synthesis based on abundant materials and fast coating processes need to be developed. With the first real production systems in the final development phase, markets like building integrated PV and mobile energy are likely to be targeted first. Given the unique form factors, there are many more applications for these novel PV technologies, especially in areas where conventional PV reaches its limits. Sub-Area 6.4 deals with the challenges of scaling up their production and ways to access an affordable terawatt capacity that the technology should allow for. This Sub-area has potential overlap with Area 8 on PV Modules and Manufacturing. Depending on the number and nature of submitted abstracts, a joint session will be considered.

*(*) Note that if your work focuses mostly on Hybrid Tandem/Multijunction solar cells, you should submit to Area 3.3*

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## Area 7: Space and Specialty Technologies

Chair: Geoffrey Bradshaw (AFRL, USA)

Co-Chairs: Mitsuru Imaizumi (JAXA, Japan)
Claus Zimmerman (Airbus, Germany)

### Area Description

Area 7 is concerned with all aspects of photovoltaic power generation subjected to extreme environments. The space and near space environment combines UV light, particle radiation, extreme temperatures and vacuum, to name a few of the environmental factors. Papers are thus welcome that deal with the entire breadth of PV under these conditions, from cell and material technologies up to complete systems. The associated sub areas are Space Solar Cells and Space PV Systems, which includes solar panel and blanket technology as well as solar arrays and structures. With typical long lifetimes, e.g. up to 15 years in GEO, combined with the inability to service the space PV systems, reliability and the correct prediction of the on-orbit performance is of key importance and will be covered in the Flight Experience and Reliability sub-area. Of particular interest are ground based degradation experiments, cell and material degradation studies, flight experiments, and on-orbit measurements.

Area 7 also welcomes a wide range of specialty technologies such as mobile solar power (MSP), flexible and lightweight PV, and PV that operates in non-traditional environments such as on UAVs and automobiles. These topics are of interest for the Specialty Technologies sub-area.

Two trends within this general context of space PV deserve special attention. The first one is "low cost" specifically for space applications. Constellations of several hundred satellites are being envisaged to provide space based broadband services. For such constellations to be economically viable, the cost of space PV has to be reduced by a factor of 5-10. Area 7 welcomes papers related to low-cost aspects of solar power specifically related to the space environment. Also of high interest are new panel, blanket, and array concepts compatible with low cost production.
The second topic of special interest is very high power systems. The largest space PV systems today are capable of delivering 20 - 30 kW of power. With the success of electric propulsion, there is growing interest in significantly higher power systems as an enabler for solar electric interplanetary science missions or near earth servicing capabilities. Therefore novel rigid and flexible planar solar array technologies as well as space solar concentrator array technologies are of interest, which can be scaled to 100 kW and beyond.

We highly encourage contributions, particularly from students who are working in relevant research areas. We invite your papers on any subjects related to space PV described above, and look forward to your contribution!

### Sub-Area 7.1: Space Solar Cells: Including Radiation Effects and Calibration

*Sub-Area Chairs:* *Don Walker (The Aerospace Corporation)*
*Wolfgang Guter (Azur Space)*
*Takeshi Ohshima (QST)*

This sub-area focuses on novel photovoltaic device approaches, modelling, and recent developments in high performance photovoltaic materials and devices for space applications. Although III-V multijunction architectures dominate space PV, this sub area is not limited to this material system nor is it limited to multijunction cells. Radiation hardening technologies that enable longer on-orbit capability are sought in this sub-area. Contributions dealing with the AM0 measurement and calibration of solar cells also belong to this area. Low-cost cell concepts that apply to the space environment are welcome.

**Sub-Area 7.2: Space PV Systems: Including Panels, Arrays, Structures, and Space Environment Impacts**

*Sub-Area Chairs:* *Bao Hoang (Space Systems Loral)*
*Mikael Thibaudeau (Thales Alenia Space)*
*Hiroyuki Toyota (JAXA)*

This sub-area focuses on technology developments associated with high-altitude and space PV systems at all component levels required for providing power on a spacecraft. It aims to bring together the individuals who are developing advanced solar panel, blanket and array concepts with the traditional photovoltaic technologists, in the hope that a fuller understanding of the mutual design restrictions will aid in developing higher reliability, higher performance space solar arrays. This sub-area covers integration of space solar cells onto rigid panels and flexible blankets all the way through advanced solar array concepts.

Technologies required for electrostatic discharge control, stabilization against ionizing radiation (e.g., UV, particles), interactions with electric propulsion subsystems and development of space solar concentrator technologies, incorporating both the optical concentrating element as well as the solar cell thermal control element are included as well. Of particular interest in this area are papers dealing with the behavior of module technology under the space environment. This includes studies on individual materials relevant for space solar modules. Also of interest are papers that describe 'New Space' approaches to lower cost, standardized solar panels both fixed and deployable, for smallsat (including Cubesat) constellations.

Contributions are sought for all power classes, from the microsatellite power range up to the several 100 kW range, with design consideration from low to high voltage arrays, which are required for large spacecraft for new telecommunication services or solar electric propelled deep space missions. To this end, papers with a mechanical focus are explicitly encouraged in this area. Also welcome are contributions that deal with platform aspects and their interaction with the solar array.

**Sub-Area 7.3: Flight Experience and Reliability of Space Photovoltaic Power Systems**

*Sub-Area Chairs:* *Scott Billets (Lockheed Martin)*
*ESA Representative (ESA)*
*Shirou Kawakita (JAXA)*

This Sub-area deals with the on-orbit performance and reliability of space photovoltaic power systems and components. An essential aspect are the results from on-orbit experimentation and operation of PV power systems and their analyses. Reliability

assessments via experimentally determined degradation behavior, e.g. due to particle irradiation or contamination, are encouraged. In this context, papers addressing the end-of-life performance with the help of degradation modelling are also of high interest. Papers dealing with reliability improvements due to particular qualification approaches and test standards are welcome. Papers covering cell and power system testing using CubeSats are also encouraged.

**Sub-Area 7.4: Specialty PV: Flexible, Lightweight and Cost-effective Mobile Solar Power for Terrestrial and Space Applications**

*Sub-Area Chairs:* *Phil Jenkins (NRL)*
*Roberta Campesato (CESI)*
*Tatsuya Takamoto (Sharp)*

This Sub-Area covers progress on the development of Mobile Solar Power (MSP) systems and applications and other specialty PV. The MSP system development includes flexible and lightweight solar cells, sheets and related integration systems. Papers are sought that describe the development of thin cell technologies including material growth, cell fabrication and testing. Papers covering developments of flexible solar sheet fabrication methods, studies on improvement of sheet durability; ruggedness and overall energy generation are invited. Papers discussing cost reduction technologies for both cell production and cell integration for use in non-traditional environments are encouraged. Development of photovoltaic sheets for systems applications such as battery charging, portable power, powering flexible electronics, solar powered UAVs (Unmanned Aerial Vehicles), and emerging technologies such as PV for automobiles covering both the military and civilian energy power application are of interest in this sub-area.

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## Area 8: PV Module Manufacturing, Systems, Power Electronics and Energy Storage

Chair: Pierre Verlinden (*Trina Solar, China)*

Co-Chairs: Wilfried van Sark (*Utrecht University, The Netherlands)*
Michael Kempe *(National renewable Energy Laboratory, USA)*

### Area Description

The remarkable decrease in the levelized cost of energy (LCOE) generated by photovoltaic systems is largely attributed to the significant improvements in module performance, engineering, and manufacturing over recent years, as well as standardization throughout the entire supply chain and cost reduction in system installation. New concepts, new materials and assembly technologies are being developed for PV modules and will further reduce costs and increase performance. Systems designs and new development in power electronics for smart energy management, including energy storage, have a significant impact on the cost of solar electricity.

Area 8 is seeking papers describing significant advances in PV module design and manufacturing, techniques for component testing and system monitoring, system design, power electronics for power conversion and smart energy management, as well as energy storage systems. We also invite papers describing advances in technology and modeling for balance-of-system components such as trackers, inverters, and power optimizers, and for building integration of PV systems. Papers on innovative deployment and new applications of PV technologies are particularly encouraged.

Papers reporting completed work that is accompanied by validation from the field, laboratory testing, or comprehensive modeling will be given preference for oral presentation.

### Sub-Area 8.1: Module Materials, Design, Manufacture, and Production

*Sub-Area Chair: TBD*

In Sub-Area 8.1, abstracts are invited that describe new concepts, new materials and methods for module production. Of particular interest are: double-glass modules, bifacial modules, modules with shingled cells, new materials for backsheets, encapsulants, glass, or interconnects; new techniques or materials for module assembly to reduce cost, increase efficiency or enhance reliability; and novel module electrical configurations to improve resilience to partial shading. We also welcome submissions describing state-of-art methods or new methods for module manufacturing, module characterization, power and energy rating, including: quality assurance of module materials and subcomponents; statistical process control; automation of module assembly.

### Sub-Area 8.2: System Design, Optimization and Performance

*Sub-Area Chair: TBD*

In Sub-Area 8.2, abstracts are invited that describe new concepts for photovoltaic systems, method of system optimization, field results and analysis. In particular, we welcome

submissions describing system design and system performance results for bifacial modules, tracker PV systems, PV systems on water, on-grid or off-grid systems, comparison with system modeling. New mathematical or empirical models for PV systems including bifacial modules, with or without trackers, are encouraged to be submitted in this Sub-Area 8.2. Note that papers related to forecasting and solar resource should be submitted under Area 9 and power electronics methods for optimization in sub-area 8.4.

**Sub-Area 8.3: Building- or Consumer Electronic-Integrated and Mobile Photovoltaics**
*Sub-Area Chair: TBD*

Submissions related to new applications of PV, such as building-integrated photovoltaics (BIPV), Consumer Electronic-integrated PV or Mobile PV, should be submitted in Sub-Area 8.3. This Sub-Area focuses on PV products that integrate building elements and solar cells to form a PV array that is an integral part of a building (facades, roofs, or other element). Technical, manufacturing, and architectural aspects will be considered. Contributions on integration into infrastructure such as noise barriers are welcomed. Additionally, papers presenting methods to integrate PV technology into portable consumer products, automotive applications of PV or other mobile applications of PV, and flexible PV products are of great interest.

**Sub-Area 8.4: Power Electronics and Cyber-security**
*Sub-Area Chair: TBD*

This Sub-area is designed for presentations and discussions about power electronics, inverters, DC-DC converters, maximum-power-point trackers (MPPT), micro-inverters, optimizers, module-level power electronics (MLPE), module-level or system-level monitoring, electronic anti-theft devices, rapid shutdown, etc. Novel concepts and designs are particularly invited, as well as real-life demonstrations of power and energy efficiency improvements. Regarding cyber-security, papers including technical aspects of protection against cyber-attacks are also encouraged to be submitted in this Sub-Area. Note: Studies on inverter's functions specifically to support grid integration and related to regulations to support cyber security are recommended to be submitted to Area 10.1. Submissions regarding reliability issues associated with cyber-security should be submitted in Area 9.4.

**Sub-Area 8.5: Energy Storage and Smart Energy Management Systems**
*Sub-Area Chair: TBD*

Sub-Area 8.5 welcomes abstracts describing, at a system level, advances related to energy storage technology, smart energy management systems and demand control (hardware and software), when integrated with a PV array, including residential, commercial, utility-scale and mobile applications. Novel technologies, innovative designs, new energy management concepts are particularly encouraged to submit in this Sub-Area. Note: Topics related to address grid integration issues are encouraged to submit to Area 10.1.

## Area 9: PV Reliability, Solar Resource and Forecasting

Chair: Sarah Kurtz (NREL, USA)

Co-Chairs: Juzer Vasi (IIT Bombay, India)
Max Koentopp (Q Cells)

### Area Description

Solar energy now supplies ~ 2% of worldwide electricity and substantially more in some locations, (e.g. approaching 10% in Hawaii, where the 45th IEEE PVSC will be held). The reliability of solar electricity has increased in importance because 1) it now represents a cumulative investment of greater than one trillion dollars or euros, and 2) the integrity of the electrical grid in many locations could now be compromised by incorrect forecasts or unanticipated outages of PV systems, especially when PV is supplying more than 50% of the local electricity on an instantaneous basis. Area 9 addresses all aspects of predictability, reliability, durability, quality, and security throughout the value chain and extending to include knowledge of the available solar resource, the opportunity of the system to deliver the electricity into the grid, and, even, possible threats from cyber attacks. Topics especially critical to the success of the PV industry include: up-to-date understanding of our ability to forecast the output of PV plants on a day-to-day and year-to-year basis, what is being observed for deployed products, the physics of degradation and failure modes, the development and field validation of accelerated tests for all components, best practices in Design-for-Reliability, manufacturing Quality Assurance, understanding soiling, measuring and forecasting the solar resource available to PV systems, security against cyber attacks, and development and acceptance of standards and test protocols to ensure safety and reliability of PV systems.

### Sub-Area 9.1: Reliability Field Experience

*Sub-Area Chairs:* *Ralph Gottschalg (Loughborough University, UK)*
*Anil Kottantharayil (IIT Bombay, India)*

This Sub-area focuses on statistics of types of failures, data analysis techniques for field data, analysis of mechanisms of observed degradation and failures, electrical and mechanical impacts of failures, degradation trajectories, and long-term operation models of PV plants. Submissions may include (but are not limited to) observations and analysis of observations from deployments of all PV technologies, methods of analysis of such data, and models or reviews that paint the big picture of what is happening in the real world. We are especially interested in studies of the effects of adding batteries to on-grid PV systems.

### Sub-Area 9.2: Accelerated Testing and Quality Control for Consistently Reliable and Durable PV System Components

*Sub-Area Chairs:* *Nancy Phillips (DuPont, USA)*
*Tadanori Tanahashi (AIST, Japan)*
*Christos Monokroussos (TUV Rheinland, China)*
*Adrian Haering (Solar Edge, Germany)*

*Vivek Gade (Jabil, USA)*

PV system components (including PV modules, cables, power electronics, batteries, etc.) are subject to thermal cycling, damp heat, electrical bias, ultraviolet light, and mechanical stresses that result in a variety of failure mechanisms such as corrosion, metallization fatigue, electronic component failure, aging of materials, and breakage. The exact nature of the degradation will vary with the type of component. Inverters may experience problems with software or transistor failures; PV modules may exhibit light-induced degradation, potential-induced degradation, damage to device passivation layers, and delamination; materials may discolor, crack, or bubble. This Sub-area welcomes papers on identification and elucidation of the chemistry and physics of these or other failure mechanisms, accelerated stress tests and acceleration factors, modeling of degradation and failure rates, and critical quality controls in manufacturing. We are especially interested in studies of how the variability of the manufacturing process is included in degradation models to assess the uncertainty in the predictions.

**Sub-Area 9.3: Effects of Soiling on PV**

*Sub-Area Chairs:* *Elisabeth Klimm (Fraunhofer ISE, Germany)*
*Sonia Diniz (Brasil)*
*Ben Figgis (QEERI, Qatar)*
*Alan Lyons (ARLD, USA)*

Soiling can be a major factor in power plant performance. This Sub-Area focuses on studies of soiling, ground- and satellite-based forecasting of soiling rates, methods for evaluating such rates, cleaning solutions, materials for anti-soiling coatings, tests for anti-soiling coatings (both artificial soiling to test functionality and abrasion testing to test for durability), studies of durability with respect to cleaning, modeling soiling losses for different climate conditions, and fundamental physics of soiling. Papers on novel anti-soiling technologies as well as techniques for evaluating the best cleaning methods, including how long robots will last are also encouraged.

**Sub-Area 9.4: Safety and Cyber Security of PV Systems**

*Sub-Area Chairs:* *Annabelle Lee (USA)*
*Bengt Jaeckel (UL, Germany)*
*Adrian Haering (Solar Edge, Germany)*

The durability and safety of PV modules, power electronics, and batteries is increasingly in focus. For example, new inverter safety requirements specified by the National Electric Code in the United States include arc /ground fault detection and rapid voltage-reduction capability. The adoption of specific safety features varies from country to country. Improved functionality and documentation of safety features of PV systems will be the focus of this Sub-area, as well as novel methods for fire prevention, arc detection and mitigation, shock

hazards, ground and series arc faults, mechanical integrity, and inspection procedures. The addition of batteries to some PV systems is adding new safety challenges and is of special interest to this sub-area, as the price of batteries is dropping and the value of installing batteries is increasing in areas with high PV penetration. As PV is supplying a larger fraction of our electricity, the possibility of cyber attacks on PV inverters or other control systems is of increasing concern, both because of loss of power and loss of data, which may compromise control of the grid. We hope to include a special session on cyber security, so encourage submissions on all aspects of the topic.

**Sub-Area 9.5: Solar Resource Measurement and Uncertainty Assessment**

*Sub-area Chairs:* *Anton Driesse (PV Performance Labs, Germany)*
*Jeff Newmiller (DNVGL, USA)*
*Jose Ruiz-Arias (Solargis, Slovakia)*

Solar resource measurements can be critical to all stages of PV projects, including development, commissioning, and operation. This sub-area welcomes papers on solar resource measurement and characterization either by ground-based or remote sensing techniques. Submissions that present various technologies' ability to quantify solar resource and investigate the associated uncertainty are preferred, especially those that examine the differences between the available thermal energy vs. the energy usable by PV modules due to their technology-dependent spectral responses. Additional topics of interest include measurement equipment functioning in the field, approaches to reducing cost of acquiring solar resource data, separation of global irradiance into the direct and diffuse components, transposition methods to the plane of array, time series vs. typical-year data for solar resource characterization, high-resolution data for PV applications (e.g., synthetic generation of 1-min solar irradiance time series) and analysis of multiple years of data to characterize random and systematically varying historical changes in solar resource. In general, better solar resource data reduces the uncertainty in estimating long-term energy production as well as in execution of a performance guarantee and monitoring the health of a system. Therefore, novel techniques for quantifying resource-related project risk for financing applications are also of great interest. Topics that address forecasting of the solar resource for plant operation or grid integration should be submitted to 9.6.

**Sub-Area 9.6: Solar Forecasting for PV Integration**

*Sub-Area Chairs:* *Jan Kleissl (Univ. California San Diego, USA)*
*Lourdes Ramirez (CIEMT, Spain)*
*Rodrigo Escobar Moragas (PUCC, Chile)*
*Joakim Widén (Uppsala University, Sweden),*
*Dazhi Yang (SIMTech, Innovis, Singapore)*

This topic focuses on the development and use of solar power forecasts in ways to best integrate PV into the electric grid. Papers solely on solar irradiance forecasting models will also be considered, with preference given to submissions of novel models based on ground, satellite, and/or numerical weather prediction data and evaluation of model performance against persistence forecasts. Topics related to PV grid integration can include research in both solar forecast models and associated impacts on grid reliability and economics. Papers can address behind-the-meter PV or focus on utility-scale PV plants. Preferred submissions in this topic area will target new insights into ways solar forecasting will enable the electric grid to successfully operate under high penetration PV with the goal of causing minimal economic and technical impacts. Non-technical studies of forecasting should be submitted to Area 10.

## Area 10: Grid Integration, Policy, Deployment & Sustainability

Chair: Izumi Kaizuka (RTS Corporation, Japan)

Co-Chair: Arnulf Jäger-Waldau (EC Joint Research Center, Italy)
Robert Margolis (NREL, USA)

### Area Description

The Grid integration, Policy, deployment & sustainability area provides an opportunity to discuss aspects required to ensure the long-term success of the PV industry. It represents an extension of the traditional scope of the conference where current concerns and strategies to increase the adoption of PV as a major electricity source will be discussed.

### Sub-Area 10.1: Grid Integration, High-penetration PV and Energy Storage

*Sub-area Chair:* *Yzuru Ueda (*Tokyo University of Science, Japan*)*
*Erika Brosz (NRG Renewables,USA)*
*Thomas Stetz, THM University of Applied Sciences*
*Ben Kropski (NREL, USA)*

High penetration of both distributed and utility-scale PV systems on the electrical power grid and the variability and unpredictability of PV output introduce a host of challenges for electrical utilities to manage. This Sub-area solicits papers addressing all aspects of grid integration, from advanced inverter functionality (LVRT, Volt/VAR) for supporting grid stability to energy storage technologies such as electric vehicles and stationary storage batteries to detailed distribution feeder network analysis methods and related studies. Application of the "Internet of Things" (IoT) to address further integration of PV is also encouraged.

### Sub-Area 10.2: Government, Policy and Financing

*Sub-area Chair:* *Gaëtan Masson (Becquerel Institute, Belgium)*
*Keiichiro Sakurai (AIST, Japan)*

This topic focuses on strategies to sustain or accelerate high PV growth rates and rapid cost reductions through government, policy, and financing models that are critical to the success of PV deployment. The installed costs of a PV system declined more than 50% between 2010 and 2017, yet certain market barriers continue to inhibit wide scale PV deployment. This Sub-area solicits papers that will help conference participants better understand the government, policy and finance considerations that are paramount to overcoming these barriers.

### Sub Area 10.3: Sustainability

*Sub-Area Chair:* *Garvin Heath (NREL, USA)*
*Keiichi Komoto (MHIR, Japan)*
*Andreas Wade (First Solar GmbH, Germany)*

This area seeks submissions with a broad, systems-level perspective on the sustainability of PV, throughout the life-cycle. These can include perspectives on material supply (*e.g.* improving efficiency of raw material extraction, concerns related to critical or scarce materials), manufacturing (*e.g.* dematerialization, efficiency gains), usage (*e.g.* influencing user behavior, encouraging adoption), end-of-life (*e.g*. recycling technologies, toxicity concerns, disposal pathways) and other aspects of the life-cycle. Novel approaches and results regarding assessing the environmental impacts of PV are particularly encouraged. Multi-disciplinary work combining economic and/or social impacts is also invited. Submissions that consider manufacturing sustainability and recycling might be combined for a joint session.

**Sub Area 10.4: Workforce Development and Education**

*Sub-Area Chair:* *Linda Koschier (UNSW, Australia)*
*Ingrid Weiss (WIP, Germany)*
*Eddy Blokken (NTU, Singapore)*

This topic focuses on original education methods to prepare the workforce for jobs associated with various aspects of photovoltaic research, manufacturing, systems design and deployment, and grid integration. Innovative education methods can include but are not limited to interdisciplinary approaches in education, new teaching methods, online education, and hands-on learning.

**Sub Area 10.5: International Collaborative efforts**

*Sub-Area Chair:* *Pius Hüsser (Nova Energie, Switzerland*)
*Lv Fung (IEE CAS,China)*

*Lenny Tinker (US DOE, USA)*At the end of 2016, global PV installations reached about 300 GWdc, with an annual increase of about 75 GWdc in 2016 and will be in the 100 GWdc range in 2018. In 2018 Photovoltic generated electricity can contribute with up to 2.5% to the world-wide electricity demand. While this percentage represents still a small contribution, PV's growth is at such a pace that it could become a significant source of electricity and modify radically the way how the world is powered in the coming decade. To overcome current obstacles and achieve further deployment of PV power generation, various international collaborative efforts have been created, such as IEA PVPS, the Global Alliance of Solar Energy Research Institutions (GASERI), and the International Solar Alliance. This subarea encourages researchers to share their efforts to date and to discuss potential areas for expanded collaboration.