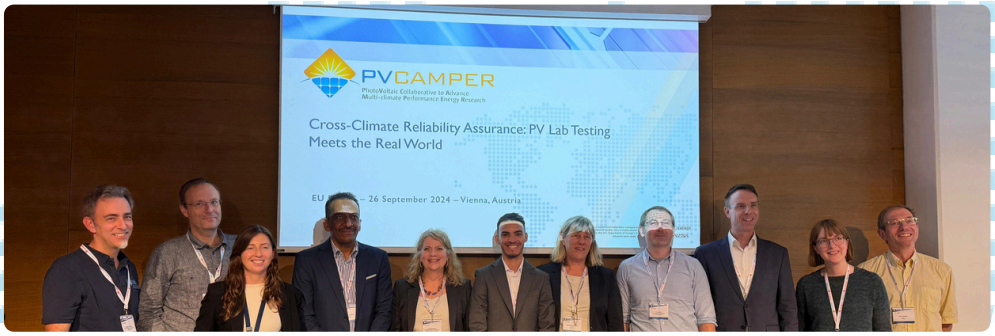
PHOTOVOLTAIC COLLABORATIVE TO ADVANCE MULTI-CLIMATE AND ENERGY RESEARCH

PVCAMPER
PhotoVoltaic Collaborative to Advance Multi-climate Performance Energy Research

A global consortium of leading research institutions

















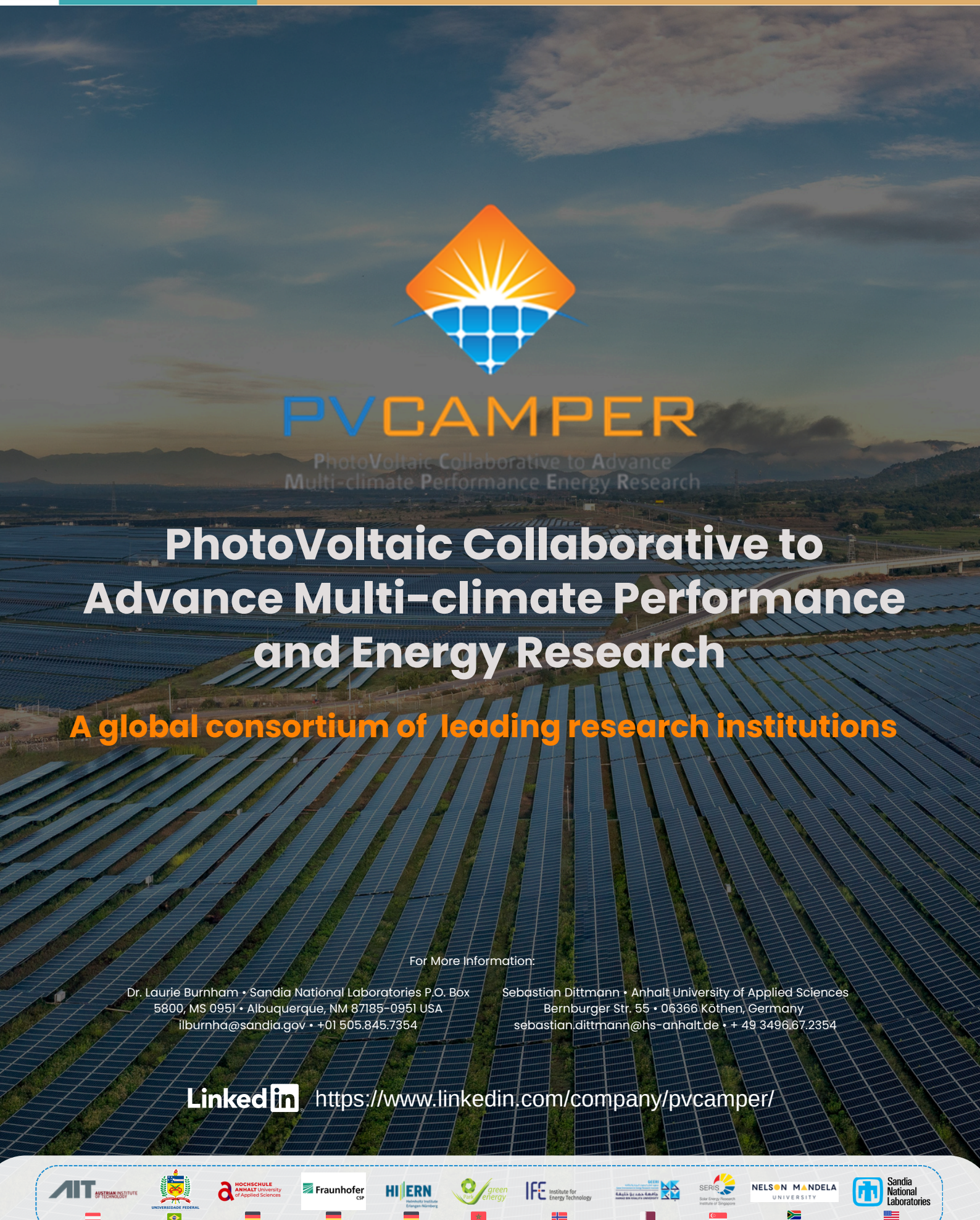
https://energy.sandia.gov/programs/pvcamper

AIT Austrian Institute of Technology
Universidade Federal
Hochschule Anhalt University of Applied Sciences
Fraunhofer CSP
HI ERN Helmholtz Institute Erlangen-Nürnberg
green energy park
IFE Institute for Energy Technology
SERIS Solar Energy Research Institute of Singapore
Nelson Mandela University
Sandia National Laboratories

Sandia National Laboratories

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LinkedIn https://www.linkedin.com/company/pvcamper/

AIT Austrian Institute of Technology · Universidade Federal · Hochschule Anhalt University of Applied Sciences · Fraunhofer CSP · HI ERN Helmholtz Institute Erlangen-Nürnberg · green energy park · IFE Institute for Energy Technology · SERIS Solar Energy Research Institute of Singapore · Nelson Mandela University · Sandia National Laboratories

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Sandia National Laboratories

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Introduction
Overview

Formed in 2018, PV CAMPER is a global consortium of research institutions committed to collaboration and to data-sharing in order to advance photovoltaic (PV) research and expand solar markets.

To date, PV CAMPER has 14 member institutions and a network of 19 field sites that span both hemispheres and most major climate zones. Each member operates one or more field laboratories and conducts extensive research on multiple PV topics. In addition, members must meet PV CAMPER requirements for instrumentation, data collection and O&M. The result is a unique international network of leading solar research institutions that generate high-fidelity cross-climate data to advance PV R&D and validate emerging technologies.



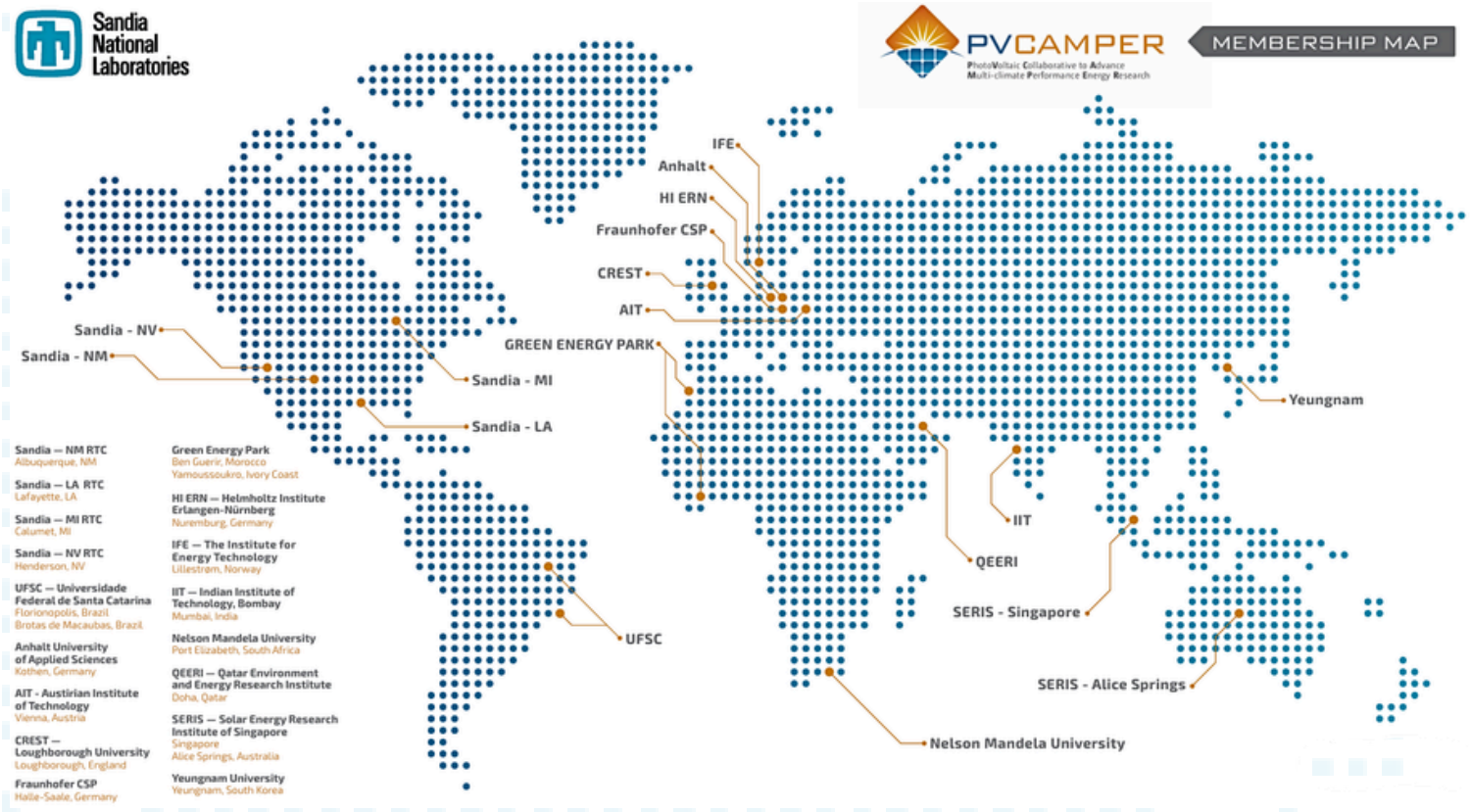
Images of irradiance sensors at six field sites: (clockwise from top left) albedometer and plane-of-array (POA) pyranometer in Michigan, USA; POA pyranometer and PV-modules in Halle, Germany; GHI and DNI sensors in Köthen, Germany; irradiance sensors in Florianopolis, Brazil; POA pyranometer and reference cells on a reference system in New Mexico, USA.

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PV CAMPER's 14 member institutions and 19 research sites are globally distributed, providing a unique technical platform for crossclimate research.

Member Organizations

- Austria: Austrian Institute of Technology (AIT) - Marcus Rennhofer
- Brazil: Universidade Federal de Santa Catarina (UFSC) - Ricardo Rüther
- Germany: Anhalt University of Applied Sciences - Sebastian Dittmann
- Germany: Fraunhofer Center for Silicon Photovoltaics (CSP) - Ralph Gottschalg
- Germany: HI ERN — Helmholtz Institute Erlangen-Nürnberg - Ian Marius Peters
- Great Britain: Loughborough University - Tom Betts
- India: Indian Institute of Technology (IIT) - Bombay, Narendra Shiradkar
- Morocco and Ivory Coast: Green Energy Park - Said Elhamaoui
- Norway: Institute for Energy Technology (IFE) - Mari Ogaard
- Qatar: Qatar Environment & Energy Research Institute (QEERI) - Amir Abdallah
- Singapore and Australia: Solar Energy Research Institute of Singapore (SERIS) - Thomas Reindl
- South Africa: Nelson Mandela University - Ernest Van Eyk
- South Korea: Yeungnam University - Soo-Young Oh, Honorary Member
- USA: Sandia National Laboratories - Laurie Burnham

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Organizational Objectives

Accelerating solar capacity worldwide requires confidence in 1) the cross-climate performance of emergent, high-efficiency PV technologies; 2) the accuracy of irradiance and other measurements needed for yield comparison and simulations; and 3) the identification of local environmental contributors to long-term reliability. To help meet these challenges, PV CAMPER:

- Fosters collaborative R&D in the areas of PV performance validation and reliability.
- Provides a global platform for evaluating new PV technologies and for identifying and quantifying the factors that contribute most to climate-specific efficiencies.
- Generates best practices for data collection to increase the accuracy and global applicability of performance models.
- Develops a technical basis for matching new technologies, including novel cell and module types, to their operating environments (spectral sensitivities, irradiance characteristics, temperature range, etc.).
- Supports the solar industry by validating new products across a range of climates.

Value to the Global Photovoltaics Community

PV CAMPER's network of research institutions reflects a common goal: the desire to foster and grow a community that can support a robust solar-energy future. Collectively, this organization offers:

- Repository of high-fidelity meteorological and PV performance data from geographically and climatically diverse sites.
- Broad expertise in such areas of PV research as soiling losses, uncertainty drivers (cloud persistence, moisture, airborne particulates) and spectral responsiveness.
- Data to support the design and optimization of PV systems for specific operating environments.

Specific Areas of R&D Interest

- Cross-climate module degradation.
- Emerging technologies (perovskites).

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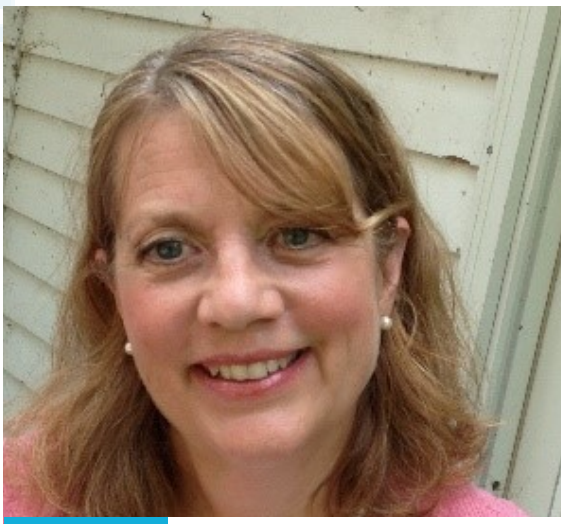
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PV CAMPER Leadership

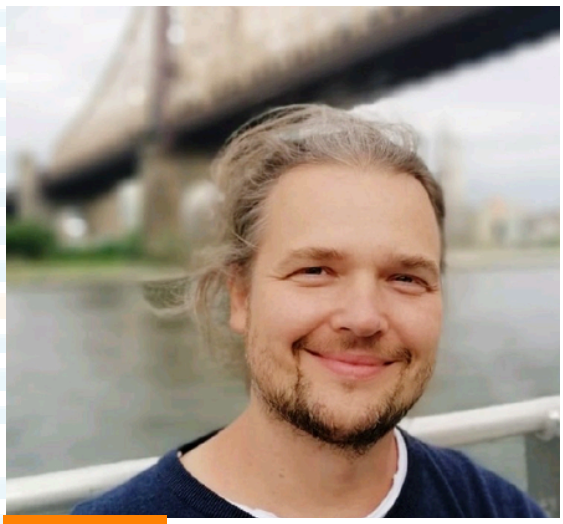
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PhotoVoltaic Collaborative to Advance Multi-climate Performance Energy Research

PV CAMPER is governed by an Executive Committee, members of which are elected every two years to ensure equal representation.



LAURIE BURNHAM

Chair



SEBASTIAN DITTMANN

Vice-Chair



MARCUS RENNHOFER

Director for Research



SAID ELHAMAOUI

Director for Outreach

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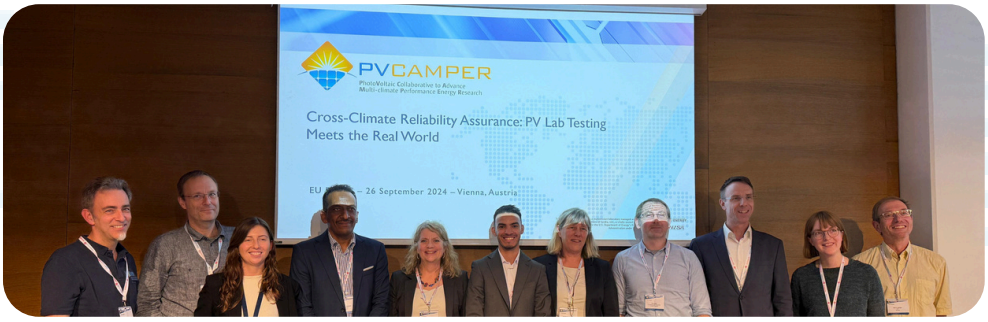
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Conferences & Workshops

- PV Days in Brazil, "Performance Enhancement and Reliability of Large-Scale Photovoltaic Power Plants, 28 April 2022.
- EU PVSEC 2023, "Cross-Climate PV Performance and Reliability: Why Global Data Are Critical to a Reliable Solar Future." 21 September 2023, Lisbon, Portugal..
- EU PVSEC, 2024. "Cross-Climate Reliability Assurance: PV Lab Testing Meets the Real World, 27 September 2024, Vienna, Austria.,
- EU PVSEC, 2025. "It's Not Just About the Module: PV System Reliability and the Little Things That Matter," 23 September 2025, Bilbao, Spain.















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Who Are We?



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Austrian Institute of Technology (AIT)

Austria | Vienna
Website: www.ait.ac.at
PV CAMPER member since: 2024

AIT in Numbers

- Years of PV research: 25
- Researchers: 20+
- Publications: 100+
- Industry-funded R&D projects: 20+

Field sites:
Vienna (48.269° N, 16.427° E) — warm temperated humid climate (Cfb)
Seibersdorf, (47.978° N, 16.508° E) — warm temperated humid climate (Cfb)

Overview

The Austrian Institute of Technology GmbH (AIT), is Austria's largest non-university research institute with 7 highly specialized research and development centers. The Center for Energy is oriented towards sustainable energy infrastructure, decarbonization of industrial processes and plants, and innovative technologies and solutions. The PV research team offers scientific support in R&D, certified standard testing, characterization, long term out-door testing and analysis, simulation and modelling to all relevant PV topics as power forecasting, failure detection, ageing and long-term energy production. AIT works closely with academia as well as excellence networks and international committees like IEC TC82, ESMC, ETIP, EERA JP PV).



History & Background

PV research at AIT began in before 2000 with the implementation of the photovoltaics laboratory which is one of the longest active in Europe. The photovoltaic laboratory of the AIT (Austrian Institute of Technology) stands for precision and innovation in the quality assurance of photovoltaic modules. With state-of-the-art technology and comprehensive testing procedures, the laboratory supports manufacturers, investors, installers and operators of PV power plants in the testing and validation of PV modules to ensure the highest standards of quality, safety and durability.

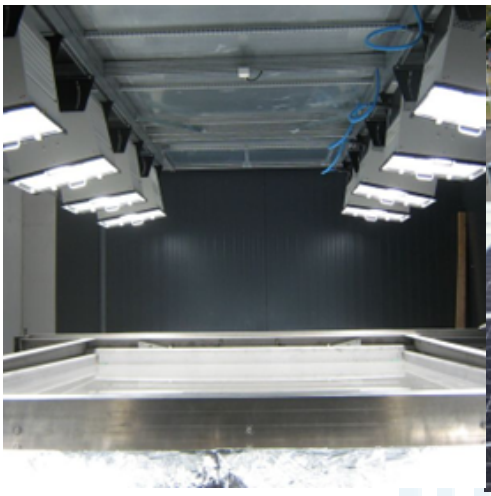
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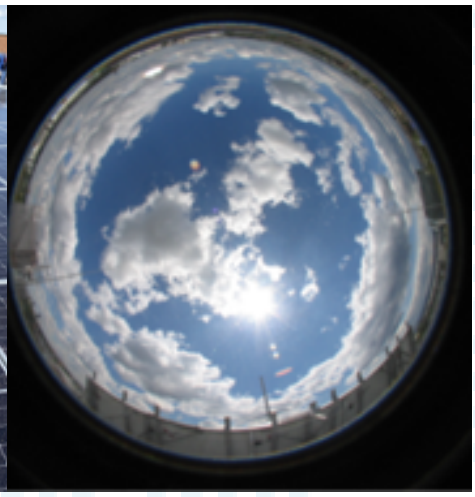
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PV Infrastructure & Test Facilities

- High precision outdoor PV module test stand, long term test bed at AIT Vienna
- 400 kW PV plants at the AIT campus Seibersdorf rooftop
- 64 kW connected to the H2 electrolysis demonstrator PH2önix
- High precision accredited PV test laboratory for quality assurance for photovoltaic modules, special applications and efficiency measurements
- Climate simulation and accelerated ageing facilities
- Traceable calibrated meteorological measurement: irradiance. air and module temperature, wind speed and direction, relative humidity, rainfall, cloud picture
- Spectral irradiance measurements on horizontal plane UV – NIR
- Advanced (electro-) optical characterization indoors and outdoors (IR, EL, PL, UVF)
- Pulsed (3x3 m^2) and static (3x4 m^2) sun simulation on module level as well as static sun simulation (20x20 cm^2) for prototype devices





PV Research Topics & Expertise

- Quality assurance, long-term durability and precise efficiency measurements for photovoltaic modules, validation of PV modules for special applications and efficiency measurements
- Ageing and degradation mechanisms, modules and plants failures and performance
- Advanced characterization of standard and new technologies, failure and impact
- Technology specific evaluation: yield, early degradation, long term degradation; new technologies and their behavior (e.g. bifacial, perovskite)
- Harmonization and standardization for stabilization, power rating and yield assessment
- Monitoring and digitalization strategies for plant operation and optimization
- Predictive maintenance and performance analysis for standard and sparse data conditions
- Digital plant models, e.g. digital twins, analytic models, machine learning and AI models
- Reliable PV plant operation by measurement, ontological descriptions and digital models
- Climate change or extreme weather impact on PV power output and yield in specific climata
- Operation, monitoring and analysis of hybrid power plants including PV, BESS and hydrogen electrolysis
- Techno-economic evaluation of hybrid PV-power plants

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Universidade Federal de Santa Catarina (UFSC)
Fotovoltaica-UFSC

UNIVERSIDADE FEDERAL DE SANTA CATARINA

Brazil | Florianópolis
Website: www.fotovoltaica.ufsc.br
PV CAMPER member since: 2018 (founding member)

Fotovoltaica-UFSC in Numbers

- Years of PV research: 29
- Researchers: 30+
- Publications: 400+
- Industry-funded R&D projects: 20+

Field sites:

Florianópolis, Brazil (27.4° S, 48.4° W) — humid subtropical climate (Cfa)
Arinos, MG (15.7° S, 45.9° W) — tropical savanna with dry winter climate (Aw)

Overview

Fotovoltaica-UFSC is a leading Brazilian research group with strong expertise in PV systems, battery energy storage systems (BESS), electric vehicles (EVs), green hydrogen (GH2), building-integrated photovoltaics (BIPV), and agrivoltaic systems (AgriPV), with a focus on performance, reliability, and energy yield under real operating conditions. Based at the Federal University of Santa Catarina, the group integrates long-term outdoor monitoring, advanced instrumentation, and modeling, and works closely with industry partners and PV plant owners through consulting services, field diagnostics, and performance assessments, supporting both academic research and real-world decision-making across diverse climatic contexts.



History & Background

PV research at UFSC began in 1997 with the implementation of the first grid-connected PV system in Brazil. Over the years, Fotovoltaica-UFSC has expanded its scope to include BESS, EVs and GH2, becoming a national reference in outdoor testing, performance analysis, and reliability studies across multiple energy technologies. The group contributes to the development of best practices for assessing climate-specific impacts on energy systems and has extensive experience collaborating with industry, utilities, and international research networks.

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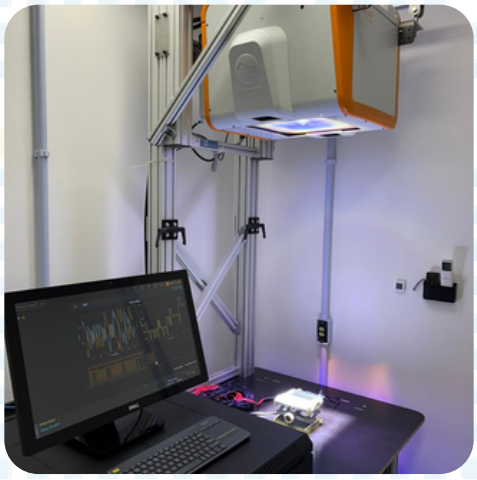
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PV Infrastructure & Test Facilities

- Automated outdoor PV test bed for individual modules and small devices, with a total of 48 independent measurement channels, 1-minute IV-curve acquisition, and synchronized module and environmental monitoring
- Fully monitored bifacial PV power plant (~100 kWp) for performance evaluation and rear-side irradiance studies
- Agrivoltaic PV systems (~100 kWp), including detailed monitoring of environmental, crop, and PV performance variables for layout optimization and crop–energy interaction studies
- Building-integrated photovoltaic (BIPV) systems (~300 kWp) deployed across a range of architectural typologies and integration concepts
- World-class meteorological station (GHI, DNI, DHI, air module temperature, wind speed and direction, relative humidity, rainfall)
- Soiling monitoring setups
- Spectral irradiance measurements on horizontal planes and tracking systems
- Thermal monitoring of modules and systems
- LED solar simulator for large-format cells and modules, enabling controlled testing and characterization of current and emerging PV technologies
- Advanced diagnostic techniques, including aerial infrared thermography (IR / IRT) and electroluminescence (EL) imaging







PV Research Topics & Expertise

- PV performance assessment and energy yield analysis
- Climate-specific impacts on PV systems, including temperature, humidity, soiling, and over-irradiance events
- Bifacial PV systems and rear-side irradiance characterization
- Spectral effects on PV performance and energy yield
- Real-world performance evaluation of current and emerging PV technologies
- Reliability, degradation, and failure analysis of PV systems and components
- Performance modeling
- PV power plant optimization, monitoring, and diagnostics
- Hybrid power plants, integrating PV, BESS, and other generation sources
- Off-grid hybrid PV systems, including BESS and diesel/genset integration for isolated communities
- Second-life PV modules, focusing on performance, reliability, and reuse potential

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Anhalt University of Applied Sciences (HSA)

Germany | Köthen (Anhalt)
Website: www.hs-anhalt.de, www.agripvplus.org
PV CAMPER member since: 2018 (founding member)

HSA in Numbers

- Years of PV research: 20+
- Researchers: 10+
- Publications: 100+
- Funded R&D projects: 10+

Field sites:
Bernburg, Germany (51.7° N, 11.7° E) — Temperate oceanic climate (Cfb)

Overview

Anhalt University's Photovoltaic Research Group focuses on the characterization of PV modules and systems, Building-Integrated Photovoltaics (BIPV), and Agrivoltaics (AgriPV). Our core expertise lies in performance and energy-yield measurements, as well as yield prediction. To ensure the highest accuracy, our test facility is equipped with high-tier sensors providing high-quality weather data for long-term outdoor monitoring and the development of new measurement methods. As a University of Applied Sciences, we bridge the gap between research, education, and knowledge transfer by working closely with industrial partners. A key highlight of our work is the **AgriPVplus Research Center**, which follows a highly interdisciplinary approach. We bring together experts from agriculture, photovoltaics, and biodiversity to create holistic solutions. By investigating how solar infrastructure impacts soil health, crop yields, and local ecosystems, we ensure that our energy solutions support both food security and ecological conservation.



History & Background

Anhalt University of Applied Sciences is one of the strongest research universities in Germany. It has developed into a significant scientific center in the Anhalt region and drives innovation. The photovoltaic research is developing sustainable energy solutions through cutting-edge technology. This expertise is directly integrated into our academic programs. We offer a specialized Master's degree in Photovoltaic Engineering Science, designed to equip the next generation of engineers with advanced technical skills and practical research experience.

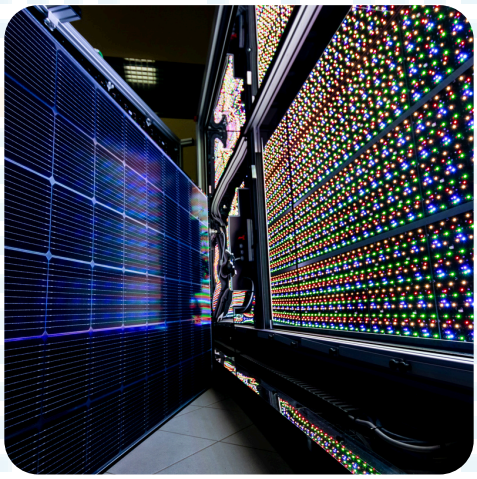
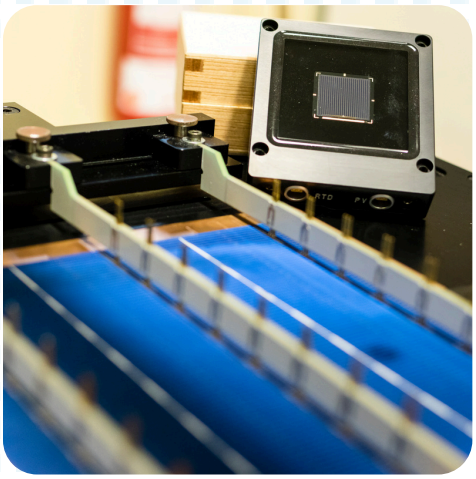
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PV Infrastructure & Test Facilities

- Outdoor PV test field for individual PV modules measurements, 1-minute IV-curve acquisition, and synchronized module and environmental monitoring
- Fully monitored grid-connected PV systems of mono-polycristaline and thin-film technology (~30 kWp)
- Bifacial PV systems with different module technologies and different orientations, e.g., facade integration
- Three AgriPVplus demonstrators with I) vertical east-west orientation (~65 kWp) and II) east-west tracking system with agriculture and biodiversity (~100 kWp), and III) east-west tracking system with grassland (~340 kWp), all as comprehensive multifunctional land use systems (Agriculture, Photovoltaic and Biodiversity), including detailed monitoring of electrical, meteorological, crop, and abiotic parameters for layout optimization and crop-energy-biodiversity interaction studies
- World-class meteorological station (GHI, DNI, DHI, spectrum, air temperature, wind speed and direction, relative humidity, rainfall)
- Spectral irradiance measurements on horizontal planes and east-west orientation
- LED solar simulator for PV cells and PV modules, enabling controlled testing and characterization of current and emerging PV technologies

PV Research Topics & Expertise

- PV performance assessment and energy yield analysis
- Climate-specific impacts on PV systems
- Bifacial PV systems and rear-side irradiance characterization
- Spectral effects on PV performance and energy yield
- Real-world performance evaluation of current and emerging PV technologies
- Reliability, degradation, and failure analysis of PV systems and components
- Performance modeling
- PV power plant optimization, monitoring, and diagnostics
- Multifunctional land use PV systems (AgriPVplus), integration and optimization of agrivoltaic systems, and biodiversity

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Fraunhofer Center for Silicon Photovoltaics (CSP)

Germany | Halle (Saale)
Website: www.csp.fraunhofer.de
PV CAMPER member since: 2018 (founding member)

CSP in Numbers

- Years of PV research: 19
- Researchers: 30+
- Publications: 100+
- Industry-funded R&D projects: 50+

Field sites:
Halle (Saale), Germany (51°29′ N, 11° 58′ O) — climate classification (Cfb)

Overview

Fraunhofer CSP conducts applied research across the entire crystalline silicon photovoltaic value chain. Core topics include manufacturing concepts, high-precision solar cell characterization, innovative module technologies and detailed indoor and outdoor characteriization. A central focus of our research services and collaborative projects is the comprehensive reliability assessment of PV-modules and complete systems under controlled laboratory conditions and field operation. Our laboratories are equipped with modern research and analytics tools that enable accelerated stress testing, in-depth failure analysis, and data-driven optimization of PV systems including newest outdoor equipment to measure latests and upcomig High-Wattage PV Modles (up to 1000W). CSP offers indoor and outdoor characterization services, providing bankable performance data for industry partners and research clients. These activities strengthen energy deployment and industrial competitiveness.
Fraunhofer CSP is actively engaged in national and international standardization activities through committees such as DKE, CENELEC, and IEC, helping to shape future quality and safety standards for photovoltaics.





History & Background

PV research at the Fraunhofer Center for Silicon Photovoltaics CSP in Halle focuses on reliability, performance and quality of silicon-based solar cells, modules and systems. Established in 2007 as a joint institution of the Fraunhofer Institute for Microstructure of Materials and Systems IMWS and the Fraunhofer Institute for Solar Energy Systems ISE, CSP combines microstructure expertise with leading PV system know-how. With advanced laboratories and state-of-the-art characterization and testing equipment, CSP supports manufacturers, investors, planners and operators in qualifying and validating PV technologies, ensuring high standards of quality, safety and long-term durability under both laboratory and real-world operating conditions.

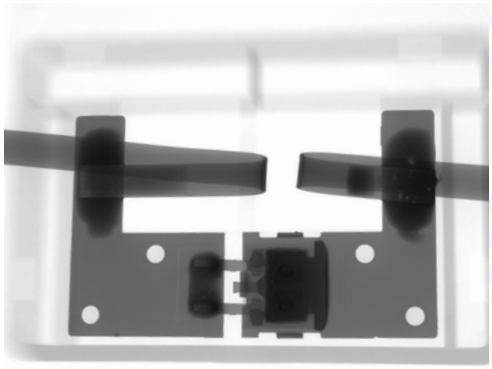
Sandia National Laboratories

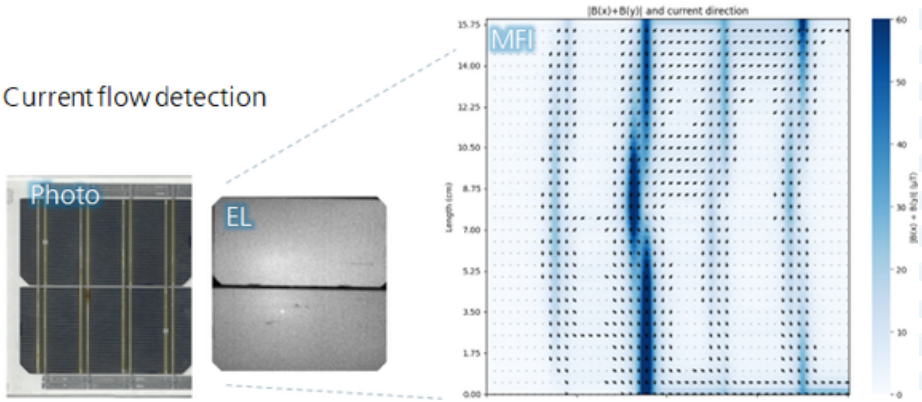
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PV Infrastructure & Test Facilities

- High precision outdoor PV module test stand (up to 1000W), long term test bed
- Multi-orientation outdoor testing with in plane irradiance monitoring
- High precision PV characterization (Flash testing, EL, IR) and test laboratory
- Advanced root cause analytical toos such as X-Ray, Magnetic field imaging (MFI) and Lock-in thermography
- Material analytics including DSC, Pyrolyse-GC/MS, Dilatometrie
- FEM Simulation
- Accellerated aging test facility from weatherometer to walk-in climate chambers
- UV- and Full spectrum indoor systems to accellerate outdoor light impact
- Various mechanical test setups, including standard mechanical load and glass testing setups (4-Point bending) for full size module size
- Special equimpent to test mounting structures









PV Research Topics & Expertise

- Advanced characterization PV cell and module characteriazation
- Root-causing for various defects from manufacturing to long term field exposure
- Quality assurance, long-term durability and efficiency measurements of PV Modules and systems including degradation, bifaciality and system layout
- PV power plant optimization, monitoring, and diagnostics
- Data-driven strategies for plant operation optimization
- Mission profile driven simulation of failure moduls utilizing a combination of Finite element modeling, indoor stress testing and outdoor data

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Forschungszentrum Jülich GmbH Helmholtz Institute Erlangen-Nürnberg for Renewable Energy (HI ERN)

Germany | Erlangen
Website: www.HI-ERN.de
PV CAMPER member since: 2021

HI ERN in Numbers

- Years of PV research: 20+
- Researchers: 10+
- Publications: 70+
- Industry-funded R&D projects: 20+

Field sites:
Erlangen, Germany (50.06° S, 12.19° W) — climate classification (Cfb)

Overview

The research department „High Throughput Methods in Photovoltaics“ of Forschungszentrum Jülich GmbH, HI ERN develops materials, processes, and technologies enables fostering sustainable, significant cost reductions in photovoltaic technologies, from small off-grid energy harvesting to large-scale production, spanning Watt to the Terawatt scales. The research integrates automated materials research, digitization, simulation, and big-data approaches with specialized PV expertise.





www.google-maps.com, access: March 11, 2026

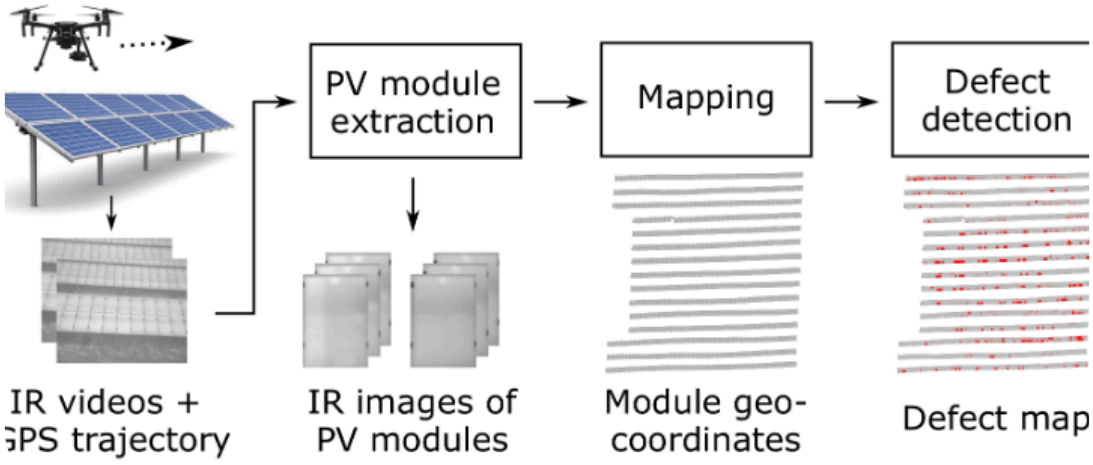
History & Background

Building on FZJ’s long-standing expertise in rapid, field-suitable optical characterization of PV modules, FZJ will contribute to PVcamperby advancing degradation, performance, and reliability assessment through non-destructive imaging and spectroscopic techniques, combined with field-deployable measurement strategies and ML-driven –supported data analysis for robust failure detection.

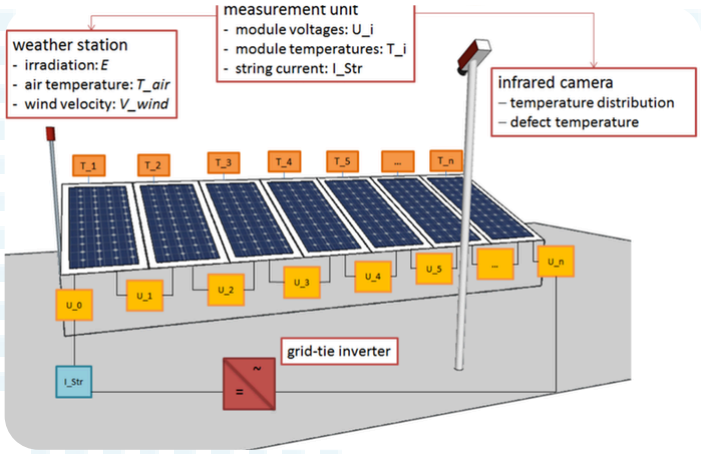
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PV Infrastructure & Test Facilities

- Ground mounted arrays with different module technologies, in total 1.5 kWp. Electrical monitoring on module and string level.
- Comprehensive weather and irradiance measurements: GHI, DNI, DHI, ambient temperature, wind speed and direction, relative humidity, air pressure, ambient temperature, bending.
- continuous monitoring of IR-anomalies
- Tools for field characterization: Aerial IR, IV-tracing, EL, PL, UVF, Riso, NIRA, NIRone, microscopy.
- Indoor module characterization and test lab: A+A+A+ Solar simulator, EL, PID, dark IV, insulation and wet-leakage testing.
- PVhawk: processing and evaluating IR imagery from solarparks , https://github.com/LukasBommes/PV-Hawk
- Labeled datasets for IR-, EL-, and NIRA-data for Machine learning







PV Research Topics & Expertise

- PV performance monitoring and analysis
- Reliability, degradation, fault detection and diagnostics
- PV power plant operations and maintenance (O&M)
- Drone and satellite-based surveillance
- Imaging techniques such as photoluminescence, UV fluorescence, Infrared thermography
- Near infrared spectroscopy for polymer analysis
- Weather analysis
- Shading analysis
- Performance of emerging PV technologies

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Green Energy Park

Morocco | Benguerir
Website: www.greenenergypark.ma
PV CAMPER member since: 20xx
(founding member)

Green Energy Park in Numbers

- Years of PV research: 10
- Researchers: 30+
- Publications: 400+
- Industry-funded R&D projects: 20+

Field sites:
Benguerir, Morocco (32.24° N, 7.95° W)— climate classification (BSh)
Yamoussoukro, Ivory Coast (6.82° N, 5.28° W) — climate classification (Aw)

Overview

Green Energy Park (GEP) is a leading Moroccan research and innovation platform with strong expertise in photovoltaic (PV) systems, renewable energy integration, green hydrogen, energy storage, smart grids, and sustainable energy applications, with a focus on performance, reliability, and technology validation under real operating conditions. Based at Mohammed VI Polytechnic University in Benguerir, Morocco, and extending its field activities through additional testing and demonstration sites including in Côte d'Ivoire, the platform combines long-term outdoor monitoring, advanced characterization facilities, digital performance analysis, and applied research. Green Energy Park works closely with industrial partners, public institutions, and international R&D networks through collaborative projects, pilot installations, field demonstrations, and techno-economic assessments, supporting both scientific advancement and practical decision-making for the energy transition in Morocco, across Africa, and beyond.



History & Background

Founded in 2017 , Green Energy Park is a renewable energy experimentation, research, and training platform based in Benguerir, Morocco. It has grown into a regional hub for applied research, technology demonstration, and innovation in solar energy and related clean-energy fields, with strong links to industrial, academic, and institutional partners across Morocco and Africa.

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PV Infrastructure & Test Facilities

- Multi-technology outdoor PV testing platform exceeding 200 kWp, located in Benguerir, Morocco, comprising 21 systems with capacities ranging from 1.2 kW to 22.22 kW for performance, degradation, and reliability assessment under desert and semi-arid conditions
- Test beds covering a broad range of PV technologies including PERC, mono-Si, poly-Si, CIS, CdTe, and CIGS, with HJT and TOPCon planned for installation
- PV module testing laboratory supporting stabilization, visual inspection, outdoor exposure, STC and low-irradiance performance assessment, hotspot detection, mechanical load testing, and wet leakage testing, following international standards
- Dedicated soiling assessment infrastructure including module-level setups, glass samples, DustIQ instrumentation, weather station support, and abrasion testing procedures
- Network of solar resource and soiling measurement stations across Morocco, including Tier-1, Tier-2, and Tier-3 automatic stations, with capabilities for albedo and soiling measurement, and extension to Yamoussoukro, Côte d'Ivoire for tropical-environment monitoring
- AAA solar simulator for controlled PV testing over an irradiance range of 100 to 1100 W/m² and temperature range of 15 to 75°C, used to assess module efficiency under varying operating conditions
- Electroluminescence (EL) diagnostics for defect detection and analysis, including work aligned with IEC TS 60904-13:2018 and bifacial PV current-voltage characterization under IEC TS 60904-1-2
- Thermal imaging diagnostics using thermal cameras to identify overheating, efficiency losses, and hot spots in PV modules, with reference to IEC 60904-12 and IEC 61215 practices
- Applied R&D capabilities in PV modeling, data collection, validation, IV-curve tracing, local weather monitoring, and agrivoltaic system design, monitoring, and field testing, including hybrid tracking control algorithms







PV Research Topics & Expertise

- PV performance assessment and energy yield analysis
- Climate-specific impacts on PV systems
- Bifacial PV systems characterization
- Real-world performance evaluation of PV technologies
- Reliability, degradation, and defect analysis
- Performance modeling and power prediction
- PV plant monitoring, diagnostics, and optimization
- Solar resource and soiling assessment
- Agrivoltaic systems design and monitoring



New Field site:
Yamoussoukro, Ivory Coast

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Institute for Energy Technology (IFE)

Norway | Kjeller
Website: www.ife.no
PV CAMPER member since: 2022

IFE Solar Energy in Numbers

- Years of PV research: 30+
- Researchers: 35+
- Publications: 500+
- Active R&D projects: 25+

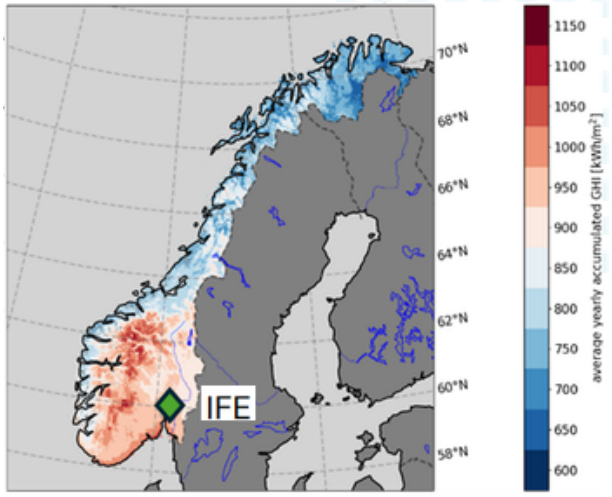
Field site:
Kjeller, Norway (60.0 N, 11.1 E) – humid continental, warm summer climate (Dfb)

Overview

IFE has operated for more than 75 years and has been active in solar energy research since 1995. IFE is Norway's leading research institute in solar technologies and conducts research spanning from in-depth material understanding of solar cell technologies to utility-scale analytics of PV power plants. Supporting its solar research, IFE has substantial activities in energy system analysis, investigating the role of PV in future energy systems, as well as research on battery technologies, hydrogen production, and advanced material modelling. IFE collaborates closely with the Norwegian and European PV industry, and maintains a strong portfolio of national and European research projects. The institute has particularly strong expertise in advanced analytics of utility-scale and floating PV systems.







Data from The Norwegian Meteorological Institute.

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PV Infrastructure & Test Facilities

- Ground mounted arrays with different module technologies, in total 23 kWp. Electrical monitoring on module and string level.
- Comprehensive weather and irradiance measurements: GHI, DNI, DHI, ambient temperature, wind speed and direction, relative humidity, air pressure, ambient temperature, spectral irradiance, albedo.
- Monitoring of module operating conditions: Front and rear plane of array irradiance, module temperature, snow cover, soiling.
- Tools for field characterization: Aerial IR, IV-tracing.
- Indoor module characterization and test lab: A+A+A+ Solar simulator, EL, climate & weathering chambers, PID, dark IV, insulation and wet-leakage testing.
- Indoor cell characterization lab: IV (with customizable spectrum), IQE and EQE (spectral response), PL & EL imaging, lifetime measurements (QSSPC, PL and µPCD), automated LiD and LeTiD measurements, bulk resistivity and sheet resistance, angular spectral reflectance and transmittance, ellipsometer for ARC characterization.





PV Research Topics & Expertise

- PV systems modelling
- PV performance monitoring and analysis
- Reliability, degradation, fault detection and diagnostics
- PV power plant operations and maintenance (O&M)
- Solar resource assessment and forecasting
- Snow impact and modelling
- Floating PV
- Building-Integrated PV (BIPV)
- Agri-PV and ecovoltaics
- PV + BESS / Hybrid PV power plants
- Drone and satellite-based surveillance

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Hamd Bin Khalifa University (HBKU) Qatar Environment and Energy Research Institute (QEERI)

QEERI
معهد قطر لبحوث البيئة والطاقة
Qatar Environment & Energy Research Institute
جامعة حمد بن خليفة
HAMAD BIN KHALIFA UNIVERSITY

Qatar | Doha
Website: www.hbku.edu.qa/en/qeeri
PV CAMPER member since: 2018 (founding member)

QEERI in Numbers

- Years of PV research: 13
- Researchers: 12
- Publications: +80
- Industry-funded R&D projects: 5

Field sites:
Doha, Qatar (Latitude 25.33° N, Longitude 51.43° E) — climate classification (BWh)

Overview

Founded in 2011 as part of Hamad Bin Khalifa University (HBKU), the Qatar Environment and Energy Research Institute (QEERI) addresses national and regional grand challenges related to energy, water, and the environment through cutting-edge research and innovation. The Outdoor Test Facility (OTF) is recognized as the premier research infrastructure across the Middle East and North Africa. Complemented by a state-of-the-art indoor laboratory, this solar energy laboratory allows us to conduct rigorous performance and reliability testing under the region's extreme arid conditions. Our work focuses on developing resilient and intelligent photovoltaic systems capable of withstanding harsh desert climates while maximizing energy yield. This mission is reinforced by over a decade of trusted partnerships with leading solar PV manufacturers, developers, EPC contractors, and O&M providers—relationships driven by the high quality of our measurements and our strict commitment to client confidentiality.



The Outdoor Test Facility (OTF), where different PV technologies are tested under real operating conditions. Approximately 35,000 m2 facility, currently installed with 500 kWp of PV technologies.

History & Background

At QEERI, solar PV research is dedicated to advancing the performance and reliability of PV systems in the challenging conditions of hot, arid desert environments. These regions are characterized by extreme temperatures, high ultraviolet (UV) irradiance, and high soiling rates, which directly impact energy yield and system lifetime. Our projects are designed to address these challenges and support Qatar's vision for decarbonization and sustainability by enabling the robust deployment of large-scale, robust solar PV technologies.

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PV Infrastructure & Test Facilities

- ·Outdoor string-level and PV module-level testbeds: standard-tilt, horizontal single-axis tracking (HSAT), vertical PV, robotic cleaning system, and single PV testbed.
- ·Meteorological station: irradiance sensors, ambient temperature, relative humidity, wind speed, and direction. Soiling sensors, particulate matter (PM) 10 monitoring, and precipitation sensors.
- ·Portable I-V curve measurement, field reflectance measurements, and insulation resistance measurements.
- Performance monitoring using data acquisition (1 minute) for PV system electrical parameters (DC and AC power, current, and voltage) and module temperature.
- ·PV system inspection: Visual inspection, Infrared (IR) imaging, Ultraviolet Fluorescence (UVF) imaging, and field Current-Voltage (IV) curve tracing at module and string levels,
- ·The Solar Technologies Laboratory is accredited according to the ISO/IEC 17025:2017 and conducts standard testing of PV modules, including a A+A+A+ solar simulator for measuring PV electrical parameters, mechanical loading test, wet-leakage test, UV chamber, and Electroluminescence (EL)



Solar irradiance sensors, soiling sensors, spectroradiometers, and UV sensors.

PV Research Topics & Expertise

- Cross-climate PV technology assessment (energy yield and degradation rate) for harsh arid environments, addressing key challenges such as soiling, high operating temperatures, high UV irradiance, and long-term reliability.
- Fault detection and early degradation of emerging PV technologies using advanced imaging techniques and root cause failure analyses.
- PV soiling: Impact assessment, soiling mechanism, dust characterization, robotic cleaning, soiling forecasting, validation of anti-soiling and anti-reflection coatings (ASC and ARC), assessing their impact on energy yield, cleaning frequency, and mechanical degradation.
- Energy yield prediction, sustainability assessment, and predictive diagnostics tailored specifically for arid hot deserts.
- Environmental degradation prediction modeling.
- Comprehensive indoor characterization of PV module Bill of Materials (BOM).

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National University of Singapore (NUS) Solar Energy Research Institute of Singapore (SERIS)

Singapore | Singapore
Website: www.seris.nus.edu.sg
PV CAMPER member since: 2018 (founding member)

SERIS in Numbers

- Years of PV research: 18
- Researchers: 60+
- Publications: 400+
- Industry-funded R&D projects: SGD 40M

Field sites:
Singapore, Singapore (1.3° N, 103.8° E) — tropical rainforest climate (Af)
Alice Springs, Australia (23.8 S, 133.9 E) — hot desert climate (BWh)

Overview

SERIS at the National University of Singapore (NUS) is Singapore's national institute for solar energy research and a globally recognised leader in photovoltaic (PV) innovation. SERIS advances solar energy adoption through research, development, testing, and consulting on PV technologies and their integration into urban infrastructure, buildings, and power systems. The institute operates world-class laboratories and testing facilities, with PV module electrical testing and grid-tied PV system measurements accredited under ISO/IEC 17025:2017 by the Singapore Accreditation Council through SINGLAS. Its research includes outdoor energy yield evaluation, module-level testing, system-level testing, and comparative assessments across climates to understand PV performance and degradation. To maximise solar deployment in land-scarce, urban environments, SERIS develops innovative solutions such as building-integrated PV, floating solar, urban solar applications, and agrivoltaics. Through its multidisciplinary team, SERIS drives technologies that support sustainable energy and tropical solar adoption worldwide.





History & Background

Established in 2008, SERIS is supported by the National Research Foundation Singapore, the Energy Market Authority, and the Singapore Economic Development Board. Since its founding, the institute has expanded its global engagement while focusing on solar technologies and services for tropical regions, particularly Singapore and Southeast Asia.

SERIS collaborates with universities, research organizations, government agencies, and industry partners worldwide. It is a sponsor member of the IEA Photovoltaic Power Systems Programme (IEA PVPS), contributing to international PV research initiatives, and an inaugural member of the Southeast Asia Energy Transition Collaborative Network (SETC), supporting regional cooperation for sustainable energy transitions. Through strong industry partnerships, SERIS has established collaborations with more than 100 companies across Singapore, the Asia-Pacific region, and beyond.

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PV Infrastructure & Test Facilities

- Outdoor PV Module and System Testing Facilities Across Different Climates – monitors PV modules and systems with research-grade accuracy, tracking electrical performance, module temperature, and cumulative energy yield, with meteorological stations recording irradiance, UV, spectrum, temperature, wind, humidity, and rainfall.
- Floating PV Research and Development – Design and evaluation of the world's largest floating PV testbed at that time, located at Tengeh Reservoir, Singapore, with SERIS managing design, construction, testing, commissioning, and scientific evaluation.
- Agrivoltaics Testbeds – Integrates agriculture with PV power using rotatable modules and sensors feeding a self-learning algorithm for automated optimisation of energy & crop growth.
- ISO/IEC 17025 Laboratory for PV Module Testing – Accredited to ISO/IEC 17025:2017, the laboratory provides electrical testing, reliability assessment, and consultancy for PV modules.
- Perovskite Solar Cell Laboratory – Facilities for fabrication and characterisation of perovskite solar cells, including mini-modules and perovskite–silicon tandem devices.
- Silicon Solar Cell Laboratory – Industrial-scale facilities with processing capability of ~100 wafers per hour for R&D on monocrystalline silicon solar cells.
- PV Device Characterisation Laboratories – Advanced tools for analysing material and device properties, supporting performance evaluation and efficiency optimisation.
- PV Module Development Laboratory – Fully equipped pilot line for industry-scale research, prototyping, and development of photovoltaic modules.







PV Research Topics & Expertise

- Module and system performance
- Floating PV systems for in-land and nearshore applications
- Urban PV solutions, including agrivoltaics
- Solar Forecasting & Grid Integration
- PV system data acquisition & monitoring
- Smart Operation & Maintenance
- PV Module Development
- Building integrated PV (BIPV)
- Perovskite-silicon tandem solar cells
- Next-generation industrial solar cells
- PV Device Characterisations

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Nelson Mandela University
Photovoltaic Research Group (PVRG)

NELSON MANDELA UNIVERSITY

South Africa | Port Elizabeth
Website: www.mandela.ac.za
PV CAMPER member since: 2026

PVRG in Numbers

- Years of PV research: 30+
- Researchers: 8
- Publications: 150+
- Active R&D projects: 10

Field sites:
Port Elizabeth, South Africa (34°00'30.13" S, 25°39'54.57" E) — temperate oceanic climate (Cfb)

Overview

The PVRG at Nelson Mandela University is a leading South African research group specializing in PV and concentrator photovoltaic (CPV) technologies. The group has expertise in performance characterization, long-term reliability, hybrid-CPV, and spectral effects. The group integrates advanced outdoor monitoring systems, spectral measurements, electrical performance analysis, and data-driven modelling. This facilitates the investigation of the influence of environmental factors such as irradiance, temperature, and solar spectrum on PV and CPV system performance.



Based within the Faculty of Science, the PVRG combines laboratory-based characterization with field-based experimentation through its dedicated outdoor PV research facility. The group collaborates closely with industry partners, utilities, and international research institutions to support technology validation and performance optimization. PVRG collaborates closely with the university spin-off company PVinsight, an ISO/IEC 17025-accredited PV testing laboratory certified by SANAS (T0956). This partnership enables laboratory and field-based evaluation of PV technologies and provides opportunities for industry-supported testing and applied research projects.

Through applied research, postgraduate training, and industry-focused projects, PVRG contributes to the advancement of PV technologies in South Africa, supporting the transition to reliable and sustainable renewable energy systems.

Sandia National Laboratories

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PV Infrastructure & Test Facilities at Nelson Mandela University

- Outdoor module characterization: several grid-tied test systems for different PV technologies, consisting of fixed-tilt, single-axis and dual-axis solar tracker systems for rapid installation of experimental systems.
- Several customized datalogging systems for monitoring current, voltage, front and rear plane-of-array irradiance and back of module temperature.
- Comprehensive weather stations monitoring GHI, DNI, DHI, reference cells, wind speed and direction, relative humidity, and ambient temperature.
- Indoor module-characterization lab: A+A+A+ solar simulators for any-size modules, including large format.
- Advanced imaging techniques: electroluminescence (EL), infrared thermal and UV fluorescence.
- Testing and PV installation training facilities.





PV Research Topics & Expertise

- PV system and module performance assessment and energy yield analysis.
- Bifacial PV module and system characterization.
- Characterization, performance analysis, and yield optimization of hybrid CPV and emerging PV technologies.
- Reliability, degradation, and failure analysis of PV systems and components.
- Advanced imaging and analysis techniques.
- Solar resource assessment and spectral measurement.
- Circularity, sustainability, and end-of-life strategies for PV technologies.
- Capacity building, training, and skills development in PV technologies.

PVRG

PVinsight







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Sandia National Laboratories
Photovoltaic Systems Evaluation Laboratory (PSEL)

United States | Albuqu.erque, NM
Website: www.sandia.gov
PV CAMPER member since: 2018 (founding member)

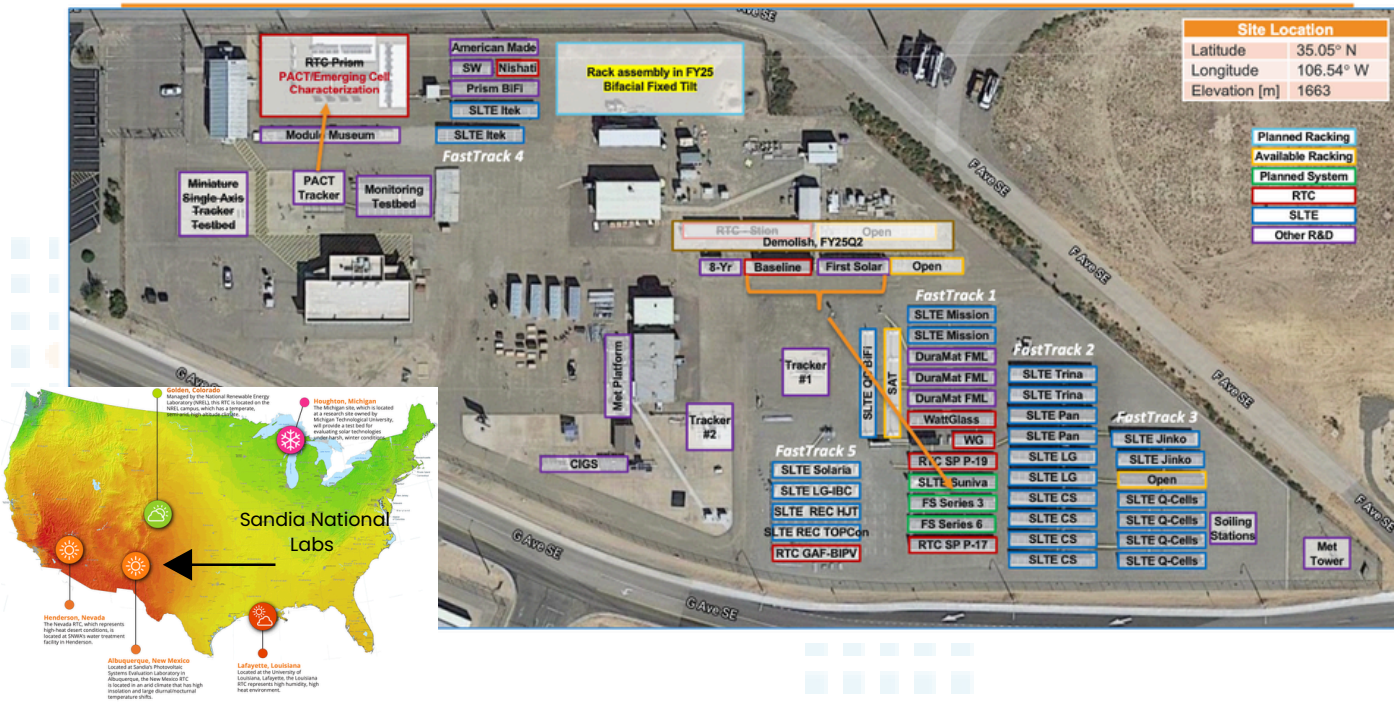
PSEL-Sandia in Numbers

- Years of PV research: 50+
- Researchers: 15
- Publications: 500+
- Active R&D projects: 10

Field sites:
Albuquerque, NM (35.1° N, 106.4° W) — cold, semi-arid climate (BSk)
Calumet, MI (47.2°N, 88.5°W) — humid continental, warm summer climate (Dfb)
Lafayette, LA (30.2°N, 92.0°W) — humid, subtropical climate (Cfa)
Henderson, NV (36.0°N, 114.9°W) – hot desert climate (BWh)

Overview

Sandia National Laboratories, a US Department of Energy National Laboratory, has been in operation for more than 75 years and at the forefront of solar-energy research for more than 50 years. Sandia is best known for its world-class indoor and outdoor characterization capabilities and is a leader in PV performance modeling and long-term performance and reliability studies, with a focus on emerging technologies and new applications. The PV team collaborates with academic and industry partners to conduct research and evaluate new products, at both the component and system levels. Sandia also leads the US Regional Test Center Program for Emerging Solar Technologies, which is a network of five field sites operated in partnership with the National Laboratory of the Rockies, the University of Nevada, Las Vegas, Michigan Technological University and the University of Louisiana,Lafayette. These sites enable cross-climate field-based research, with high-fidelity outdoor monitoring systems, and are available for industry-funded proprietary projects.



Aerial view of Sandia's PSEL facility is depicted above; the other sites in the US Regional Test Center Program, which is managed by Sandia, are depicted in the map to the left.

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PV Infrastructure & Test Facilities at Sandia

- Seven acre site with a capacity of 1MW; > 50 PV systems and >1000 modules currently installed.
- Outdoor module characterization: two programmable and configurable 2-axis trackers, including electrical and thermal performance and angle-of-incidence response (one-minute averages).
- Comprehensive weather station (GHI, DNI, DHI, reference cells, air module temperature, wind speed and direction, relative humidity, ambient temperature, heated rain gauge)
- Fixed-tilt and single-axis tracker systems, including grid-tied open racking for rapid installation of experimental systems
- Fully insulated roof platform for building-integrated photovoltaic (BIPV) systems
- Customized high-accuracy DC string-level monitoring system (current. voltage, front and rear plane-of-array irradiance
- Soiling instrumentation
- Automated daily system-status monitoring for quality assurance
- Indoor module-characterization lab: one-sun AAA flash tester for any-size modules (including large format); light soaker; EL, IR and UV imaging
- Indoor cell characterization lab: 1-sun cell tester, spectral response and reflectance and transmission measurements
- Dedicated outdoor characterization lab for perovskite and tandem-cell technologies, including small-format 2-axis tracker for electrical (automated IV curves) and thermal measurements, and fixed tilt racking for modules.







PV Research Topics & Expertise

- PV system and module performance assessment and energy yield analysis
- Climate-specific impacts on PV systems, including temperature, humidity, soiling, snow and extreme-weather events
- Long-term degradation analysis of module technologies
- Perovskite and tandem cell characterization and performance analysis
- Bifacial PV systems and rear-side irradiance characterization
- Spectral effects on PV performance and energy yield
- Cross-climate performance evaluation of current and emerging PV technologies
- Reliability, degradation, and failure analysis of PV systems and components, including electrical balance-of-systems components
- Performance modeling (Sandia leads the PV Performance Modeling Collaborative)

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Appendix
Membership Requirements

Membership has two categories: **primary and secondary.** Eligibility criteria for primary membership include an institution's technical capabilities, international reputation, geographic location and perceived value to researchers and industry.

Secondary, or associate, membership is an option for 1) research institutions that do not meet the full eligibility requirements but want to contribute data to a specific research project(s) and 2) industry members that make direct contributions to PV CAMPER in the form of equipment and/or funding.

Prospective member institutions in either category must submit a request to the PV CAMPER Chair, present their case at a PV CAMPER monthly meeting, including a detailed overview of their test facilities, characterization, monitoring and meteorological equipment, with admission to PV CAMPER based on a majority vote.

Once admitted, PV CAMPER members must sign a Memorandum-of-Understanding and agree to transmit irradiance and other data to a central database; adhere to O&M protocols; participate in collaborative R&D; and attend monthly online meetings and at least one annual face-to face meeting.

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