PV CAMPER Progress Report

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Major Goals & Objectives:

The objective of the Photovoltaic Collaborative to Advance Multi-climate and Performance Research (PVCAMPER) is to create a multi-climate research platform similar to the US DOE Regional Test Center (RTC) program. Overall, the goal is to foster collaborative research and to build an international organization dedicated to sharing data and exchanging best practices related to PV performance.

In this reporting period, we:

1) Uploaded data to the PV CAMPER database on the DuraMAT datahub
2) Negotiated a solution to the MOU bottleneck with Fraunhofer CSP and Fraunhofer USA, Inc.
3) Launched three new collaborative research projects
4) Created an Associate Member category for industry members
5) Published one PVSCC conference paper; had another paper accepted at EU PVSEC
6) Built a website and designed a PV CAMPER logo and presentation template

Project Results and Discussion:

Task 1. Formation of the Collaborative

The PV CAMPER collaborative is defined by its MOU and two-tiered membership structure. Eligibility criteria for primary membership include the institution's technical capabilities, international reputation, climatic profile and perceived value to researchers and industry. The associate membership category includes 1)research institutions that do not meet the full eligibility requirements but want to contribute data to a particular research project(s) and 2) industry members that make direct contributions to PV CAMPER in the form of equipment and/or funding.

Subtask 1.1. Member recruitment

PV CAMPER has 11 founding members, depicted in Figure 1, with the recent addition of the University of Loughborough in England.

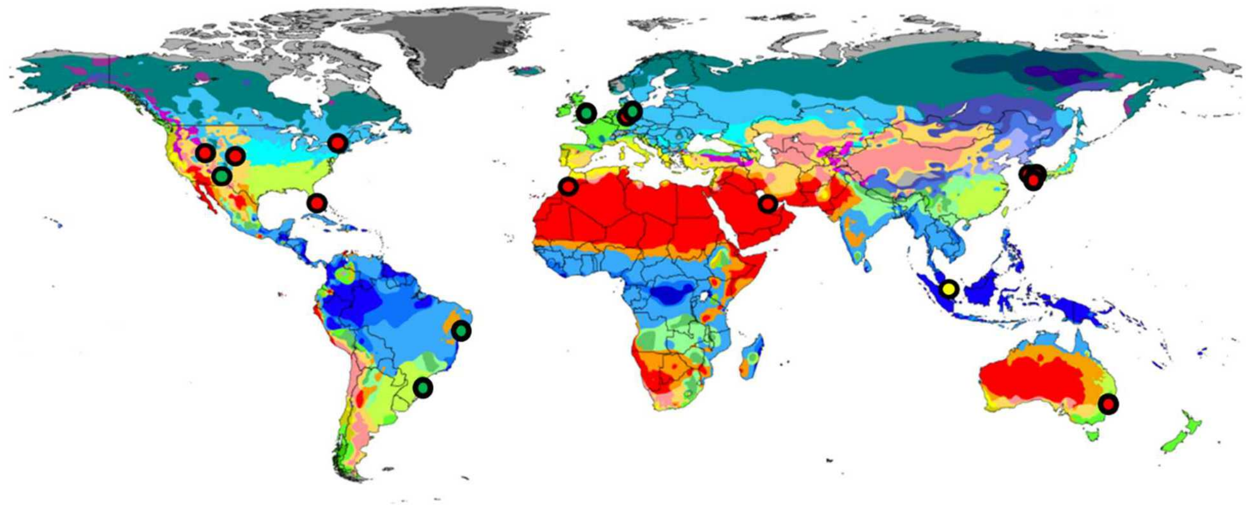

Figure 1. Global distribution of PV CAMPER members, super-imposed on a Koeppen-Geiger climate map.

Subtask 1.2. Organizational framework

PV CAMPER's Memorandum of Understanding (MOU), which defines the roles and responsibilities of primary member organizations, has been now been reviewed and approved by the full roster of PV CAMPER members and is ready for a formal group signing. The breakthrough can be attributed to legal counsel at Sandia and Fraunhofer who finally approved the MOU with the *proviso* that the document be signed by their American subsidiary as follows: "Fraunhofer USA, Inc., a research & development 501(c)3 nonprofit, incorporated in Rhode Island, on behalf of Fraunhofer-Gesellschaft's Center for Silicon Photovoltaics, with its principal location in Hale, Germany."

The document is now out for signature, with members asked to sign using DocuSign software.

Table 1. List of PV CAMPER members who have agreed to sign the MOU.

Member Institution	MOU
Anhalt University	√
Fraunhofer CSP	√
Institut de Recherche en Energie Solaire et Energies Nouvelles (IRESEN)*	√
Korea Institute for Energy Research (KIER)	√
Korea Testing Lab (KTL)	√
Qatar Environmental and Energy Insitute (QEERI)*	√
Sandia National Laboratories	√
Solar Energy Research Institute of Singapore (SERIS)*	√
Yeungnam University	√
Universidade Federal de Santa Catarina (UFSC)*	√
University of Loughborough	√
*These are in the final round of negotiation/review	

Task 2. Data-sharing and analysis

Subtask 2.1. Technical inventory

Anhalt University has completed a technical inventory of instrumentation and onsite capabilities for all member institutions. Yet to be resolved, however, is the PV CAMPER baseline PV system but discussions are underway regarding system specifications and possible funding support from a PV CAMPER associate member.

Subtask 2.2 Database construction

Sandia has completed construction of the PV CAMPER database, which is hosted on the DuraMAT datahub. The site runs on a CKAN platform and is divided into subprojects (see Figure 2), with each subproject assigned to a member institution that has authority over its own data.

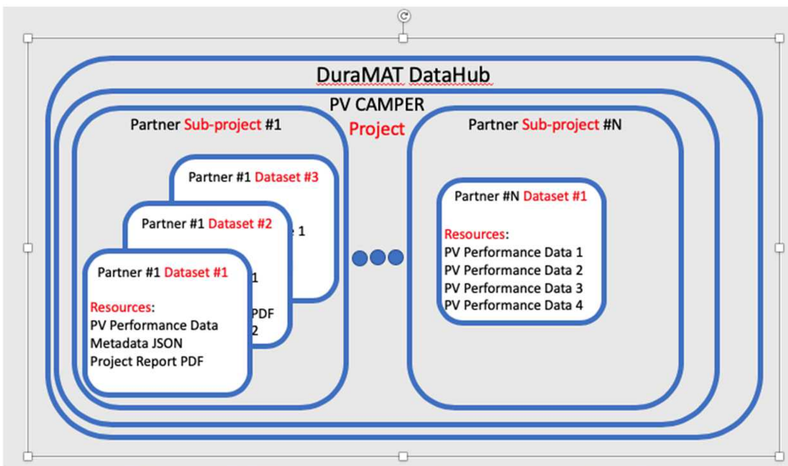

Figure 2. Architecture of the PV CAMPER database within the DuraMAT datahub. Labels in red conform to the baseline DataHub organizational structure.

Each subproject can further be divided into distinct datasets. For example, in sub-project #1 in Figure 2, three CKAN datasets are shown, each containing data and relevant files/metadata to that data. In sub-project #N, data from multiple systems are collected in a single CKAN dataset. The CKAN datasets allow users to consolidate documents and metadata (e.g., Microsoft Word and PDF files) in a single place for sharing. Tabular data is accessible for upload and download via a REST-API. Partners have "Read Only" permissions to all subprojects within the PV CAMPER Project but only the owner of the sub-project has write permission.

```
df  = pd.read_sql("SELECT * FROM my_table WHERE DATE("TmStamp") = DATE(TODAY());
records = df.to_dict(orient="records")
with ckanapi.RemoteCKAN(BASE_URL,API_TOKEN) as ckan:
    response = ckan.action.datastore_upsert(
        id=resource_id, force=True, records=records, method=method
```

Figure 3. Code for uploading data to the PV CAMPER database.

Several members have uploaded data already to the site; others are waiting until the MOU is fully signed. In the interim, a committee of researchers from Anhalt and Universidade Federal de Santa Catarina (UFSC) has formed to create a PV CAMPER nomenclature to ensure standardization of data labeling. The development of that nomenclature is informed by DuraMAT Datahub recommendations and by PV CAMPER's research projects.

Subtask 2.3 Project Plan for Collaborative Research Study
PV CAMPER members have four research projects underway, with preliminary results for two of them already accepted for conference presentations. The status of each project is presented below; Participating organizations per project are listed in Table 2, with a summary of each project to follow

Table 2. Participation of PV CAMPER members in research activities

Participating Institution	Albedo study	Back-of-Module Temperature	Over-irradiance	Condensation	Pyranometer*
Anhalt	**Lead**		●	●	
Fraunhofer CSP	●			●	**Lead**
IRESEN					
KIER					
KTL					
QEERI				**Lead**	
Sandia	●	●	●	●	
SERIS	●		●		
Yeungnam	●				
UFSC	●	**Lead**	**Lead**	●	
Loughborough	●		●		

*The pyranometer study was put on hold when COVID forced the closure of the CREST calibration lab but is still a project of interest.

1. Ground-based Albedo Measurements – led by Anhalt University
Despite the growth in bifacial PV, there are no standards for ground-based albedo monitoring and minimal albedo data available to modelers. Moreover, performance models consider albedo be constant for a substrate type when, in fact, albedo changes both diurnally and seasonally.
The objectives of this PV CAMPER study are to:

1) Establish a set of best practices for ground-based albedo measurements, which include requirements for ensuring data quality across multiple sites, including type and placement of instrumentation, and calibration and maintenance protocols;
2) Measure albedo diurnal and seasonal shifts across difference climate zones;
3) Quantify the reduction uncertainty in albedo measurements by the above technical approach;
4) Validate simulation methods for rear-side irradiance

The methodology for this study is divided into four parts, as outlined in Table 12.

Table 3. Methodology for albedo study

Part	Method
1	Quality check of instrumentation
2	Measurement of rear-side horizontal irradiance (G_{rear_hor})
3	Measurement of rear-side plane-of-array irradiance (G_{rear_poa})
4	Measurement of rear-side plane-of-array irradiance (G_{rear_poa}) in PV systems (either bifacial or monofacial)

2. Back-of-Module Temperature Study – Led by UFSC

Accurate module temperature estimation leads to more accurate energy production forecasts and to a better understanding of the PV degradation process. Yet little is known about the accuracy of different temperature-estimation models in diverse climatic conditions. This study aims to:

1) measure the temperature behavior of different PV technologies in various climate zones across the globe; and

2) evaluate the accuracy of temperature-estimation models relative to the measured data from these same sites.

This study encompasses:

- Analysis of temperature-measurement methodologies, information that is key to identifying best practices and building an international standard. Best practices include requirements for ensuring data quality across multiple sites, including type and placement of sensors, and calibration and maintenance protocols;
- The quantified reduction in field-measurement uncertainty, as demonstrated by the above technical approach;
- Assessment of the accuracy of PV module-temperature estimation models;
- Analysis of data to bring greater accuracy of PV modules and PV performance prediction.

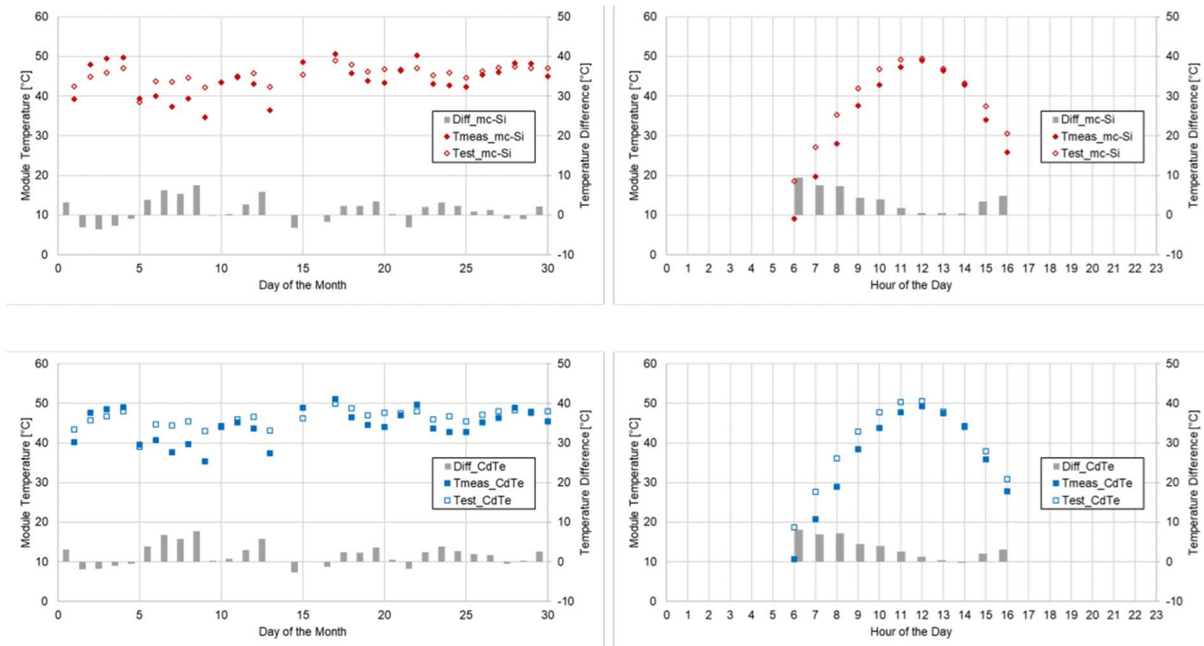

Figure 4. Preliminary results for one test site, Brotas de Macaúbas-BA, in Brazil depicting the difference in measured and estimated (Ross model) module temperature (a) daily results for September 2018 for mc-Si; (b) hourly results for September 1, 2018 for mc-Si; (c) daily results for September 2018 for CdTe; (d) hourly results for September 1, 2018 for CdTe.

This research will be presented at the virtual EU PVSEC conference in September: M. Braga, A.K. de Oliveira; L. Burnham, S. Dittmann, R. Gottschalg, B. Figgus, A. Benlarabi, T. Betts, T. Reindl, S.Y. Oh, J.H. Choi, K.S. Kim and R. Ruther, *Comparative Analysis of Module Temperature Measurements and Estimation Methods for Various Climate Zones Across the Globe*, 37th EU PVSEC, 2020.

3. Over-Irradiance – led by UFSC
Over-irradiance events, which occur when a visible cloud-brightening event (cloud enhancement- or cloud-edge effect) causes a magnification of solar irradiance, can impact the performance of utility-scale PV power plants. Under specific conditions (when the events last longer than 1 min and ambient temperatures exceed 30°C), a sudden burst of over-irradiance can blow string fuses and overload inverters, leading to energy losses.

For this study, each participating PV CAMPER member contributed one year of high-resolution irradiance data collected at a frequency of one second.

Table 4. Irradiance instrumentation for participating PV CAMPER sites

Test Site	Sampling / Averaging Intervals	Global Tilted Irradiance	Global Horizontal Irradiance	Diffuse Horizontal Irradiance
BRA-FLN	1s / -	SMP11-V Pyranometer (LT)	SMP22-V Pyranometer	SMP22 Pyranometer on tracker with shading ball
BRA-BTS	1s / -	CMP11 Pyranometer (LT)	SMP11-V Pyranometer	SPN1 Pyranometer
GER-BBG	1s / 10s	SMP10-V Pyranometer (35°)	SMP10-V* Pyranometer	SMP10-V* Pyranometer on tracker with shading ball
USA-ABQ	1s / -	CMP11-V Pyranometer (LT)	CMP22-V Pyranometer	Eppley 848 Pyranometer on tracker with shading ball
UK-LBO	1s / -	CMP11 Pyranometer (34°)	CMP11-V Pyranometer	CMP11-V Pyranometer on tracker with shading ball

* not considered in this paper

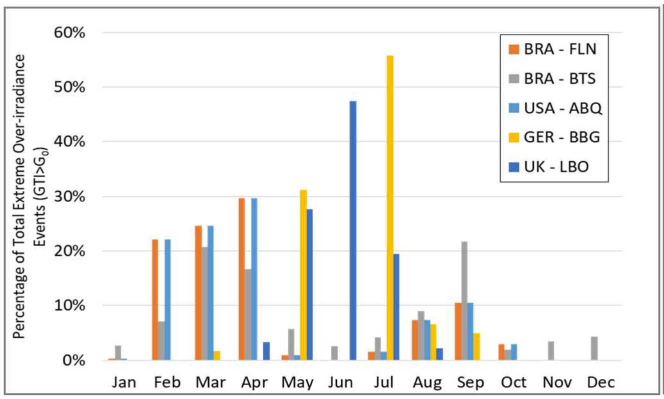

Figure 5. Monthly distribution of tilted extreme over-irradiance events ($GTI>G_0$) detected throughout a full year of data for all five test sites: BRA-FLN (orange bars), BRA-BTS (gray bars), USA-ABQ (light-blue bars), GER-BBG (yellow bars) and UK-LBO (dark-blue bars).

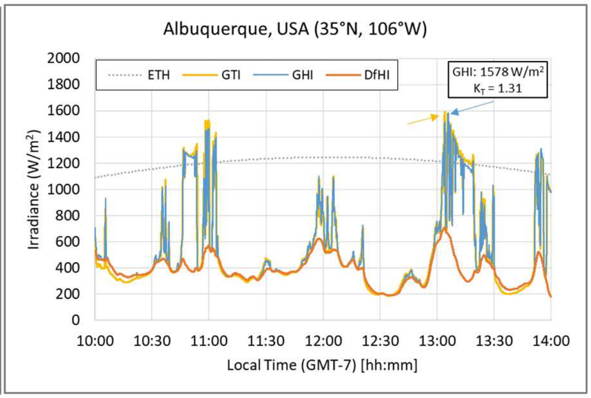

Figure 6. Monthly distribution of tilted extreme over-irradiance events (GTI>G0) detected throughout a full year of data for all five test sites: BRA-FLN (orange bars), BRA-BTS (gray bars), USA-ABQ (light-blue bars), GER-BBG (yellow bars) and UK-LBO (dark-blue bars).

Table 5. Summary of Horizontal Over-irradiance Events for Selected Sites

	BRA FLN	BRA BTS	USA ABQ	UK LBO
Number of Over-Irradiance Events	2882	11251	2361	3174
Maximum Peak (W/m^2)	1703	1802	1578	1426
Maximum Peak Date	20/01/19	27/11/19	23/04/19	15/06/19
Maximum Peak Event Duration (s)	16	80	64	2
Maximum Peak K_T	1.22	1.31	1.31	1.24
Longest Event Duration (s)	467	1159	1291	388
Longest Event Date	24/04/19	11/04/19	17/02/19	01/07/19

Results obtained so far suggest that 1) over-irradiance events are far more common at low altitudes than previously presumed; 2) a full understanding of over-irradiance as it impacts PV operations requires high frequency GHI and GTI data; and 3) over-irradiance is a serious but unrecognized concern for utility-scale power plants (for both plant design and operation), with a significant number (7.0%) of over-irradiance events lasting one minute or longer and more than half of extreme over-irradiance events occurring in quick succession.

Reference:
M. Braga, A.K. de Oliveira, L. Burnham, S. Dittmann, R. Gottschalg, T. Betts, C. Rodriguez-Gallelos, T. Reindl, R. Ruther, *Over-Irradiance Events: Preliminary Results from a Global Study,* 47th IEEE PVSC, June-August, 2020, 8pp.

4. Condensation – led by QEERI

Qualitative evidence suggests that moisture plays a major role in PV soiling but quantitative data is lacking. In particular no studies have measured condensation on fielded modules as a contributor to soiling.

The objectives of this project are to:

1) quantify the effect of module condensation on PV soiling (% of soiling variation accounted for by condensation variation);

2) determine the cause/effect of soiling quantity and composition on condensation occurrence;

3) evaluate condensation as a predictor of PV soiling rate at different geographic locations; and

4) improve the understanding, modeling and prediction of PV soiling across different climates/locations.

QEERI has built, calibrated and distributed condensation sensors (*see Figure 8*) to participating members, with the expectation that the sensor and soiling system will be set up and generating data by early August.

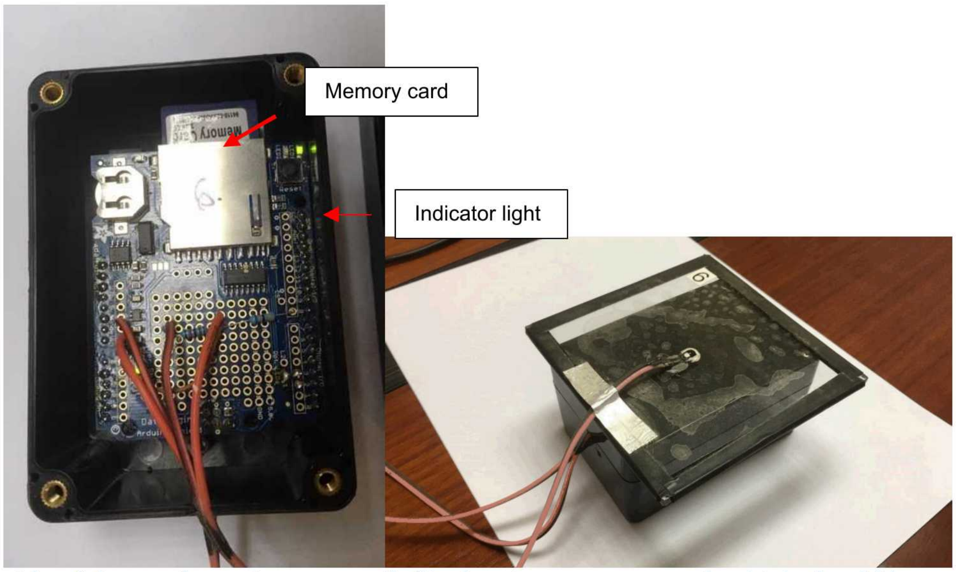

Figure 7. Inside of the condensation sensor (left), showing memory card, which should be read every two weeks and glass surface with moisture sensor (right).

Data will be collected for a minimum of one year, with the expectation that the team will collaborate on the development of a soiling model.

5. Pyranometer Uncertainty – led by Fraunhofer CSP
Pyranometers are especially critical instruments for measuring PV performance and are the baseline for any comparison between sites; it is also well known that pyranometers that have different calibration chains differ in output. To understand those differences requires careful assessment.

The objectives of this project are to:

1) Collect data on pyranometer drift across the PV CAMPER sites under a set of controlled conditions and procedures, including calibration and recalibration by the same laboratory; and
2) develop a tool that can be used by PV Camper participants to calculate point-by-point measurements and time-series-based uncertainties associated with the pyranometer.

This research project, while still of great interest, has stalled for two reasons: 1) the methodology calls for each participant to send one or two pyranometers to CREST (a fully ISO17025 accredited calibration laboratory) at Loughborough University, but Loughborough has been shut down on account of COVID19; and 2) the cost of calibration is significant, and therefore challenging, for most PV CAMPER members.

The decision to create an associate membership category and also mechanism for external funding may make this study possible but the timing is uncertain.

Task 3. Outreach and Communications

Subtask 3.1 Develop a PV CAMPER website

The PV CAMPER webpage is located at: https://energy.sandia.gov/pv-camper

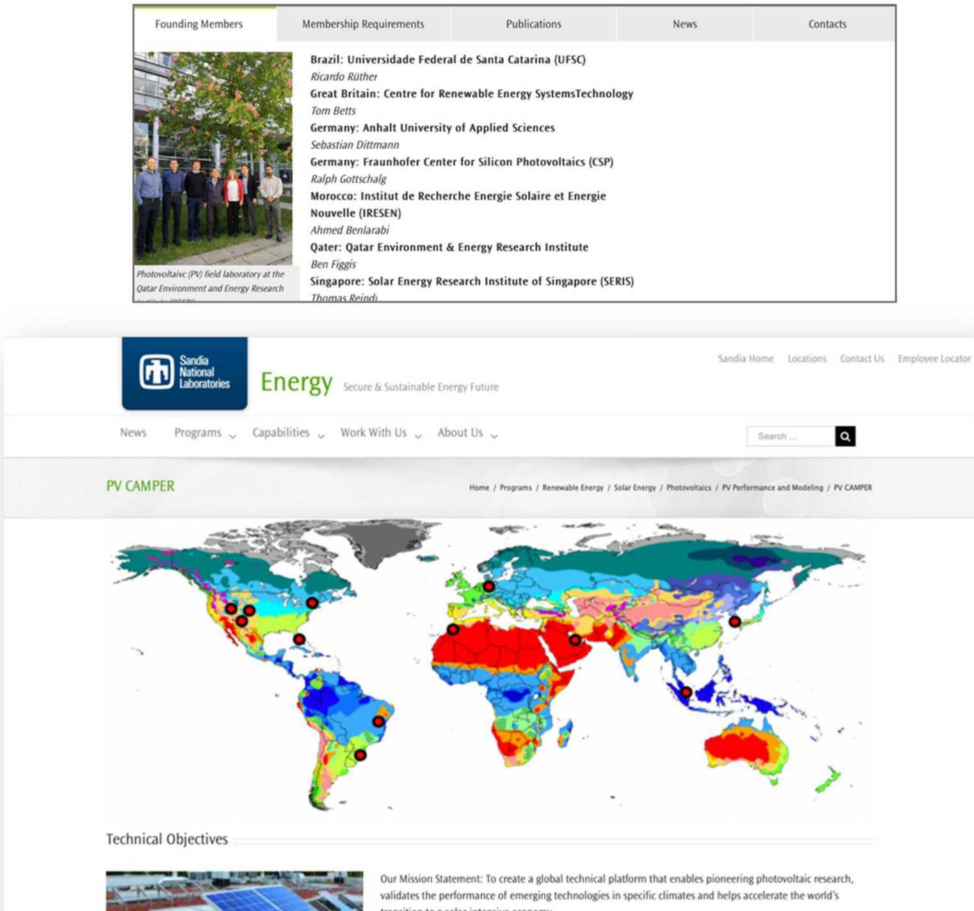

Figure 8. Screenshots of the PV CAMPER webpage.

PV CAMPER Logo

To increase organizational visibility and credibility, PV CAMPER now has its own **logo**, which was designed by Sandia Creative Services and approved by all members:

PVCAMPER
PhotoVoltaic Collaborative to Advance Multi-climate Performance Energy Research

PVCAMPER

PVCAMPER
PhotoVoltaic Collaborative to Advance Multi-climate Performance Energy Research

As a related effort, Sandia Creative Services also designed a presentation template that made its debut at IEEE PVSC conference in June:

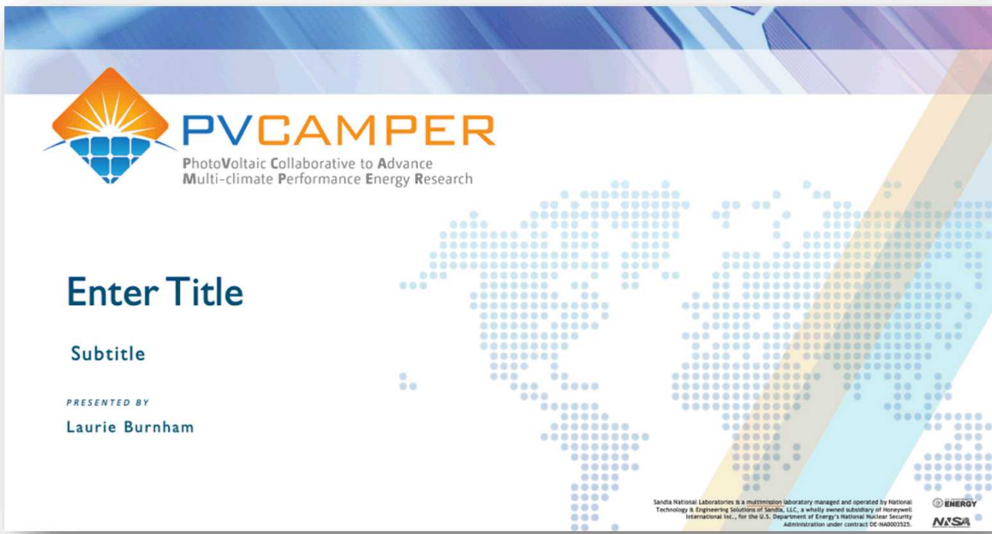

Figure 9. Title page for the PV CAMPER presentation logo

Subtask 3.2. Propose an article about PV CAMPER to a trade publication
Participants in the over-irradiance study have agreed that the results from our preliminary study should be pitched to PV Magazine. SERIS has offered to work their editorial contacts to make the pitch.

Subtask 3.3. Submit proposal to a leading conference
The following papers were accepted for presentations in 2020:

- M. Braga, A.K. de Oliveira, L. Burnham, S. Dittmann, R. Gottschalg, T. Betts, C. Rodriguez-Gallelos, T. Reindl, R. Ruther, *Over-Irradiance Events: Preliminary Results from a Global Study,* 47th IEEE PVSC, September 2020, 8pp.
- M. Braga, A.K. de Oliveira; L. Burnham, S. Dittmann, R. Gottschalg, B. Figgus, A. Benlarabi, T. Betts, T. Reindl, S.Y. Oh, J.H. Choi, K.S. Kim and R. Ruther, *Comparative Analysis of Module Temperature Measurements and Estimation Methods for Various Climate Zones Across the Globe*, 37th EU PVSEC, 2020.
- L. Burnham, Photovoltaic degradation in desert environments: a tale of two sites, PV Days Brazil, 13 March 2020. (Note: this event was cancelled on 12 March in response to a local COVID outbreak.)

Impact:
PV CAMPER has begun to have impact as gauged by the number of research projects, publications and level of engagement by member institutions.

Plans for Next Reporting Period:
The plans for next quarter include:

- Delivery of fully executed MOU (all members have signed and document is counter-signed by Sandia)
- Development of PV CAMPER by-laws, including roles & responsibilities for maintaining and leading the collaborative
- Data collection and analysis for the multiple research projects
- Delivery of *PV Magazine* article
- Presentation at EU PVSEC
- Explore funding mechanism with Anhalt
- Negotiate the terms of associate membership with TOTAL Energy
- End-of-project report

Changes/Problems
The biggest challenge at this point is the uncertainty of funding past the end of this fiscal year and Sandia's continued participation.

Participants & Collaborators
Sandia:

- Laurie Burnham, PI for the project and organizational lead.
- Daniel Riley, instrumentation consultant on the project. Mr. Riley is responsible for developing PV system monitoring platforms and has provided key input into the PV CAMPER technical platform.

International Participants

The international participants in this project provide in-kind support in the form of personnel hours, travel costs and equipment/facilities needed for collaborative research projects. We meet at a minimum once a year but may engage in person at conferences and other research-related events, such as workshops.

- Sebastian Dittmann, Research Fellow at Anhalt University in Germany, co-lead of PV CAMPER and lead for the albedometer study.
- Ralph Gottschalg, Director of Fraunhofer CSP and lead for the pyranometer study. Also participating from Fraunhofer are Matthias Ebert and David Dassler.
- Soo-Young Oh, American citizen and professor *emeritus* at Yeungnam University in South Korea.
- Ben Figgis, research program manager at QEERI in Qatar and lead for the soiling project.
- Ahmed Benlarbi head of PV module development at IRESEN in Morocco.
- Thomas Reindl, deputy CEO of SERIS in Singapore
- Carlos Rodriguez-Gallelos,SERIS

- Ricardo Ruther, professor of electrical engineering at UFSC in Brazil. Marilia Braga and Aline Kirsten, graduate students in electrical engineering also actively participate in the project and are leading both the temperature and over-irradiance research projects.
- Christopher Fell, physicist and photovoltaics expert at the CSIRO Energy Center in Australia.
- Jun-Hong Choi, engineer at Korea Testing Laboratory.
- Kyung-soo Kim, is a principal research in the photovoltaic lab at KIER in Korea.