Project Title:	PV Stakeholder Engagement Initiatives
Project Period:	1 Oct 2015 – 30 Sept 2018
Project Budget:	$312,000
Submission Date:	30 September 2018
Recipient:	Sandia
Address:	PO Box 5800, MS 1033, Albuquerque, NM 81285
Agreement Number:	SuNLaMP 30507
Awarding Agency:	DOE EERE SETO PV subprogram
Working Partners:	N/A
Principal Investigator:	Joshua S Stein Distinguished Member of Technical Staff Phone: 505-845-0936 Email: jsstein@sandia.gov

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Executive Summary: The key objectives of this project were to increase meaningful stakeholder engagement in photovoltaic performance modeling and reliability areas. We did this by hosting six workshop over the past three years, giving conference and workshop presentations and contributing to technical standards committees. Our efforts have made positive contributions by increasing the sharing of information and best practices and by creating and sustaining a technical community in PV Performance Modeling. This community has worked together over the past three years and has improved its practice and decreased performance modeling uncertainties.

Background: The PV Performance Modeling Collaborative (PVPMC) is a group started by Sandia National Laboratories in 2010 to bring together stakeholders with the aim of advancing the "state of the art" in PV performance prediction. The PVPMC hosts a technical website (pvpmc.sandia.gov), workshops, and open-source modeling function libraries (PVLIB). In 2015, IEA PVPS Task 13 formed a partnership with the PVPMC to increase international participation in this group's mission.

In September 2010, Sandia hosted the first PV Performance Modeling Workshop in Albuquerque, NM. This event brought together 50 stakeholders representing independent engineers, model developers, manufacturers, integrators, academics, and research scientists. The outcomes of this workshop are detailed in a report [1] and are summarized below.

- Models are not consistent. Even the same model run by different users may produce different answers.
- Performance models are a collection of separate model algorithms linked together.
- Performance models typically require many input parameters and variables, many of which are not know with high accuracy.
- Third party validation of models and modeling algorithms is not common but is needed.
- Models are frequently tuned or calibrated to measured field data, which is not widely available.
- Model results rarely include estimates of uncertainty or provide confidence bounds.

Prior to the workshop, attendees were asked to use the PV performance model of their choice to estimate the annual energy produced by three PV systems using standard c-SI module technologies. The 20 participants who volunteered for this "blind" study were given measured weather and irradiance data as well as PV system design information needed for input to performance models. They each ran their models and provided their results to Sandia prior to attending the workshop. The predicted annual generation for each of these model runs was compared to the measured output from the systems. An example for one of the system comparisons is shown in Figure 1. The variation in predictions from PVsyst exhibited a +/- 15% deviation. Analysis of results indicated that a lack of best practices was largely to blame for the large discrepancy in results.

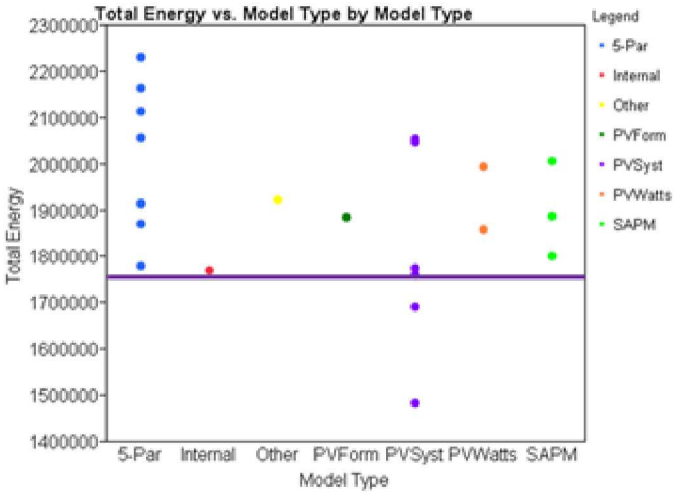

Figure 1. Variation in modeling results for annual energy from blind study [2]. Horizontal line is measured energy.

Introduction: Sandia provided critical technical input to several stakeholder engagement activities that directly supported the SunShot program goals, particularly in the PV program area. Table 1 lists these four task activities that were pursued in FY18.

Task Activities	Key Objective for FY18	FY18 Budget
1. International Energy Agency PVPS Task 13	Work with team to obtain an extension to PVPS Task 13 for ~2018-2021	$17k
2. PV Performance Modeling Collaborative (PVPMC)	Workshop in Q3, Website, Updates	$29k
3. Standards Support Activities (a) PVQAT Participation (b) UL and NEC Support	Co-lead standards development	$30k

Project Results and Discussion: This project resulted in several impactful outcomes.

International Energy Agency PVPS Task 13: Over the three-year period of this project, Dr. Stein actively participated in the following IRA PVPS task 13 Meetings:

- Albuquerque, NM USA September 2016 (Hosted by Dr. Stein at Sandia)
- Bolzano, Italy April 2016
- Canobbio, Switzerland March 2017

Activity in this working group during the FY18 period was focused on writing a workplan for the next 3-year project extension. Dr. Stein contributed to this work plan as a Subtask Lead for Subtask 1 and an activity lead for areas related to PV materials and module designs (Subtask 1.1) as well as bifacial PV (Subtask 1.2). The workplan was

completed and was presented to the IEA PVPS EXCO and was approved for the 2019-2021 project period.

Dr. Stein organized an interim Task 13 meeting that was held during the WCPEC-7 conference in Hawaii on June 10, 2018. Planned contributions were discussed among meeting participants.

The first official task meeting for the new period will be held in Hamlin, Germany (October 10-12, 2018). Dr. Stein will represent the US at this meeting.

PV Performance Modeling Collaborative (PVPMC): The work performed in this task included organization of five PV Performance Modeling Workshops and the 2018 PV Reliability Workshop that together included over 1,000 attendees. All presentations are made available on the PVPMC website (links provided below):

- 6th PV Performance Modeling and Monitoring Workshop, Cologne, Germany (October 24-25, 2016).
- 7th PV Energy Rating and Module Performance Modeling Workshop, Canobbio, Switzerland (March30-31, 2017)
- 8th PV Performance Modeling and Monitoring Workshop, Albuquerque, NM (May 9-10, 2017).
- 9th PV Performance Modeling and Monitoring Workshop, Weihai, China (December 5-7, 2017)
- PV Reliability Workshop, Denver, Colorado (February 27-March 3, 2018). Sandia helped to organize the Inverter and Balance of Systems sessions.
- 10th PV Performance Modeling and Monitoring Workshop, Albuquerque, NM (May 1-2, 2018).

This task also included release of several new version of the PVLIB Toolbox for Matlab and support for new versions of the python pvlib.

- PVLIB Toolbox for Matlab: Version 1.4. Released August 2018.
- Pvlib for python: Version 0.6.1. Released in September 2018.

We also gave an oral presentation on open source tools for PV modeling at the WCPEC-7 conference is Hawaii in June 2018.

Standards Support Activities:

PVQAT Support: Connector Reliability Standards

This project supported work aimed at improving standards related to connector reliability and firefighter safety around PV systems and also helped to organize the 2018 PV Reliability Workshop in Denver (February 27- March 2, 2018).

Major emphasis of this year's work on PVQAT was concentrated on WG10: "PV connector reliability". The PV connector qualification effort has been focused on developing a qualification standard for electric connection.

Work in this project helped to provide data relevant to IEC 61215 and 61730, which cover module surface temperatures of up to 90°C. In certain climates and installations scenarios, higher temperatures have been measured. Specifically, a substantial amount of feedback from commercial partners has been received that temperatures may reach up to +120C for US installations. Some of the visual feedback collected from field failures is shown in Figure 1. Industry has agreed that there is reason to increase the upper temperature end for module and connector testing protocols. This project helped to add two additional "High Temp" conditions for testing (90°C – 100°C and 100°C – 110°C).

Figure 1. Example of a failed connector retrieved from the field.

The group has made considerable progress in completing the qualification test plan for connectors, including chemical exposure, corrosion, mechanical pull test, UV exposure and others.

Following work described above, WG10 is in the final stages of summarizing these test procedures. Next, this test and qualification procedures will advance for consideration as and IEC spec. This is a significant step towards improving overall PV system reliability and safety.

Task 4 UL and NEC standards support

Jack Ficker presented IEEE PVSC paper “Hazard Analysis of Fire Fighter Interactions with Photovoltaic Arrays”. This conference paper received a lot of interest from both US and international experts. This work was a continuation of the work on Firefighters Safety in the proximity of PV systems.

Following earlier work at Sandia on Firefighter safety around PV systems, UL has formed a task group for a new standard for PV hazard control, UL 3741. Existing product safety standards for NFPS 70 and the NEC code require “Rapid System Shutdown” for each PV system. This name is misleading, since PV systems are not truly shutdown as a result of this action, and a PV system may take up to 30 seconds to perform this action. This task group is still active and is working on changing the name of the standard from the “Rapid System Shutdown” to “Photovoltaic Hazard Control”. The new standard will also address future safety and hazard control of PV + Storage systems, which are becoming more and more prevalent. This working group will be making recommendations for changes to NEC 2020 revision.

Conclusions: The key results of the project were its success in bringing together over 1,000 stakeholders at technical workshops and providing a central access point for presentations, open source software, and technical information about PV performance and reliability on the web.

Budget and Schedule: This project did not have any direct cost support from industry, however we did benefit from in kind support for workshop hosting and organization and voluntary PVLIB support from the following institutions: EPRI, CFV Solar Test Laboratory, University of Arizona, the Harbin Institute of Technology, Fraunhofer ISE, SUPSI, and TÜV Rheinland. Many other individuals also volunteered by contributing content to PVLIB and the website.

The table below provides a summary of the project spend plan and actual expenses by quarter. We are underspent by ~$6k.

II. Project Spend Plan				A. Federal Share Initial Plan	B. Federal Share Updated Actuals & Plan
Year	Quarter	From	To		
2015	Q4	10/1/2015	12/31/2015		$0
2016	Q1	1/1/2016	3/31/2016	$28,364	$12,850
2016	Q2	4/1/2016	6/30/2016	$28,364	$38,331
2016	Q3	7/1/2016	9/30/2016	$28,364	$10,762
2016	Q4	10/1/2016	12/31/2016	$28,364	$33,796
2017	Q1	1/1/2017	3/31/2017	$28,364	$31,027
2017	Q2	4/1/2017	6/30/2017	$28,364	$39,026
2017	Q3	7/1/2017	9/30/2017	$28,364	$27,591
2017	Q4	10/1/2017	12/31/2017	$28,364	$34,113
2018	Q1	1/1/2018	3/31/2018	$28,364	$26,277
2018	Q2	4/1/2018	6/30/2018	$28,364	$35,994
2018	Q3	7/1/2018	9/30/2018	$28,364	$16,489
Totals				**$312,000**	**$306,255**

Path Forward: The work done in this project will be expanded for FY19-21, as this workshop scope was included as part of a Core Capability project at Sandia National Laboratories. The new project, PV Performance Modeling and Stakeholder Engagement, will expand on the activities supported in FY18 and add a technical component aimed at developing new and improved PV performance modeling capabilities and sharing them as open source software.

Publications Resulting from This Work:

- Holmgren, W. F., C. W. Hansen and M. A. Mikofski (2018). "pvlib python: a python package for modeling solar energy systems " The Journal of Open Source Software 3(29): 3, https://doi.org/10.21105/joss.00884.
- Flicker et al. 2018. “Hazard Analysis of Fire Fighter Interactions with Photovoltaic Arrays “, UL Report.
- Flicker et al., 2018. “Hazard Analysis of Fire Fighter Interactions with Photovoltaic Arrays” in the 7th World Conference Photovoltaic Energy Conversion, Waikoloa, Hawaii, June 10-15, 2018.
- Holmgren, W. F., C. W. Hansen, J. S. Stein and M. A. Mikofski (2018). “Review of open source tools for PV modeling” in the 7th World Conference Photovoltaic Energy Conversion, Waikoloa, Hawaii, June 10-15, 2018.
- Stein, J. S., “Energy Prediction and System Modeling”. Chapter 11.5 in *Photovoltaic Solar Energy: From Fundamentals to Applications*. A. Reinders, P. Verlinden, W. v. Sark and A. Freundlich, eds. pp. 564-578, Wiley, 2017.
- Stein, J. S. (2017). PV Performance Modeling Methods and Practices: Results from the 4th PV Performance Modeling Collaborative Workshop, International

Energy Agency Photovoltaic Power Systems Programme. IEA-PVPS T13-06:2017: 95.

References:

[1] C. P. Cameron, J. S. Stein, and C. A. Tasca, "PV Performance Modeling Workshop Summary Report," Sandia Report, SAND2011-3419, 2011 (https://pvpmc.sandia.gov/download/4403/) .