US DOE REGIONAL TEST CENTERS PROGRAM

2016 ANNUAL REPORT

Sandia National Laboratories

IN PARTNERSHIP WITH NREL
NATIONAL RENEWABLE ENERGY LABORATORY

U.S. DEPARTMENT OF ENERGY

NNSA
National Nuclear Security Administration

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LETTER FROM THE PROGRAM LEAD

Dear Readers,

In 2016, renewable energy from photovoltaic (PV) technologies was the fastest growing electrical energy source in the US, with about 14,800 MW of new PV generation installed (SEIA's Solar Market Insight 2016 Year in Review). Recent price drops now mean that solar PV has reached grid parity in many markets, especially at utility scale. Despite this impressive milestone and growth, solar energy still only represents about 1% of the nation's electrical generation portfolio. There is still a long runway for solar PV to grow and for the US to take a lead in technology development, manufacturing and systems engineering. However, for US industry to be successful in this competitive international market they still have need for technical assistance from the US national laboratories. This is where the Regional Test Center Program makes an impact.

Specifically, PV technology developers (e.g., module or inverter manufacturers) typically do not have expertise in PV system field performance and degradation monitoring, and do not have ready access to field sites to test their products in a variety of climates. Furthermore, if and when problems arise with new technologies, as often happens, the DOE's national laboratories' experts and facilities are on hand to evaluate and propose solutions. The Public-Private partnerships established through the RTC program provide US PV industry with an edge on foreign competitors, who receive similar national support.

The RTCs have made great progress in 2016 and now are working with more than 20 PV companies and 42 different PV technologies. The data and being collected and the analyses being performed all help to strengthen the US PV industry and provide confidence to stimulate further investment in a modern and non-polluting energy source.

Sincerely,
Joshua S. Stein PhD.
RTC Program Director
Distinguished Member of Technical Staff, Sandia National Laboratories

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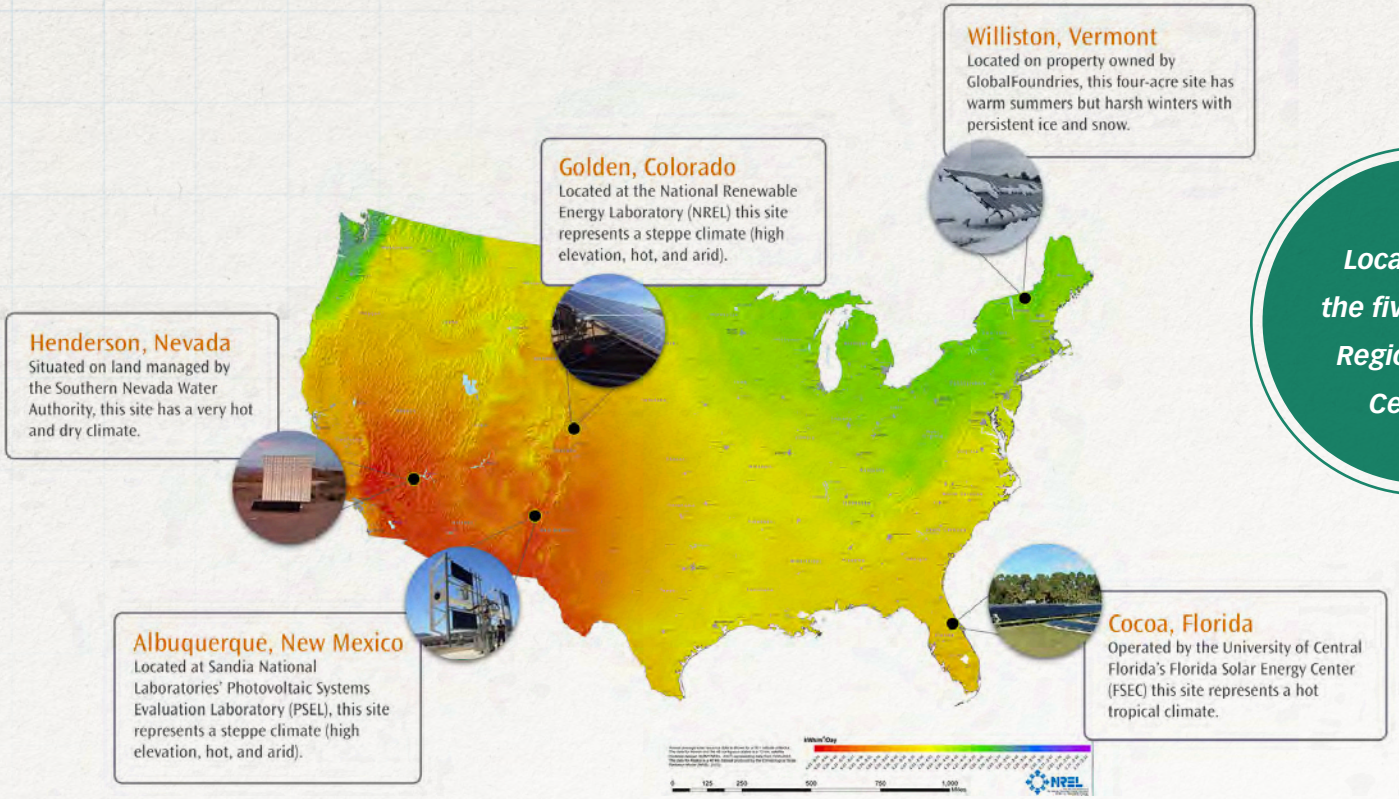
PROGRAM OVERVIEW AND OBJECTIVES

The US Department of Energy's Regional Test Center (RTC) program provides outdoor validation and bankability data for innovative solar technologies at five sites across the US representing a range of climate conditions. Data helps get new technologies to market faster and improves US industry competitiveness. Managed by Sandia National Laboratories and the National Renewable Energy Laboratory (NREL), the RTC program partners with US manufacturers of photovoltaic (PV) technologies, including modules, inverters, and balance-of-system equipment. The study is collaborative, with manufacturers (also known as RTC industry partners) and the national labs working together on a system design and validation strategy that meets a clearly defined set of performance and reliability objectives.



Locations of the five US DOE Regional Test Centers.

BACKGROUND

Launched in 2011, the primary objective of the RTC program is to collect high quality performance data and provide analysis to validate that a given technology performs as predicted over time and in multiple climates.

To that end, the RTC program:

Leverages national-laboratory expertise in PV characterization and analysis, systems modeling and reliability to support validation studies.

Supports public-private partnerships to identify opportunities to improve specific technologies/approaches.

Builds a foundation of field-based knowledge (including cross-climate performance data) to support bankability standards.

Develops new evaluation methodologies for emerging technologies.

Shares technical data publically available systems at the RTCs.

PARTNERING WITH INDUSTRY

The RTC has an outreach component to new industry partners ranging from startups to multinational corporations. Interested companies submit a proposal that describes their product(s), outlines their technical objectives and explains the value of their proposed study to the broader solar community.

Company proposals are evaluated according to the following criteria:

VALIDATING NEW TECHNOLOGIES

Scientists from Sandia and NREL, with deep expertise in performance modeling, systems reliability, data analysis, and other PV-related fields, work closely with the RTC industry partners to design customized validation studies that result in high-fidelity performance data and help advance a set of technical objectives.

This performance data can quantify the impact of climate on the performance and reliability of photovoltaic technologies and systems, quantify initial performance degradation, and drive further technical innovation and product improvement.

DEVELOPING AND EVALUATING NEW STANDARDS

One of the purposes of the RTCs is to provide an outdoor laboratory for development and evaluation of PV standards. For example, development of capacity test standards (IEC 61724-2 20161)[1] and energy evaluation methods (IEC 61724-3 2016)[2] benefit from field evaluation, and comparison with existing methods. The RTC installations provide opportunities for field trials of these methods, for the benefit of RTC partners. They also generate usage statistics for informing standards development. Other topic areas where new standards and test methods are being developed include bifacial PV module power rating,[3] and the energy gain of distributed power electronics under partial shade conditions.[4]

1 Photovoltaic system performance – Part 2: Capacity evaluation method, IEC TS 61724-2:2016.

2 Photovoltaic system performance – Part 3: Energy evaluation method, IEC TS 61724-3:2016.

3 V. Fakhfouri, "IEC 60904: Photovoltaic Devices – Part 1-2: Measurement of Current-Voltage Characteristics of Bifacial Photovoltaic (PV) Devices," Proposal 82/1044/NP, July 28, 2015.

4 Deline, J. Meydbray, M. Donovan, "Photovoltaic Shading Testbed for Module-Level Power Electronics: 2016 Performance Data Update", NREL technical report TP-5J00-62471, http://www.nrel.gov/docs/fy16osti/62471.pdf, 2016

INFRASTRUCTURE R&D IMPROVEMENTS IN 2016

The RTC program has introduced multiple innovative strategies to reduce installation and operational costs and improve data quality from fielded systems. These improvements include the installation of partner-ready grid-tied racking, standardized monitoring hardware designs, and the development of new, low-cost automated monitoring systems that measure string-level IV curves.

"Fast Track" Racking System at the NM RTC.

"FAST-TRACK" RACKING CONCEPT

The RTCs have adopted an innovative racking system, our so-called "Fast Track," which can be quickly modified to accommodate any size module and includes wire trays and equipment racking to further reduce installation time. In addition, the data-acquisition system for the fast track includes a backbone MODBUS network, allowing for easy expansion. The "fast-track" at each RTC also has plane-of array (POA) irradiance sensors, the data from which are available to all partners who have systems installed on the rack. These upgrades alleviate the need to replicate the same infrastructure for each new partner system. Sandia also reduced racking costs in New Mexico and Nevada by ballasting those systems with recycled concrete bin blocks.

LOW-COST ADVANCED ARRAY MONITORING

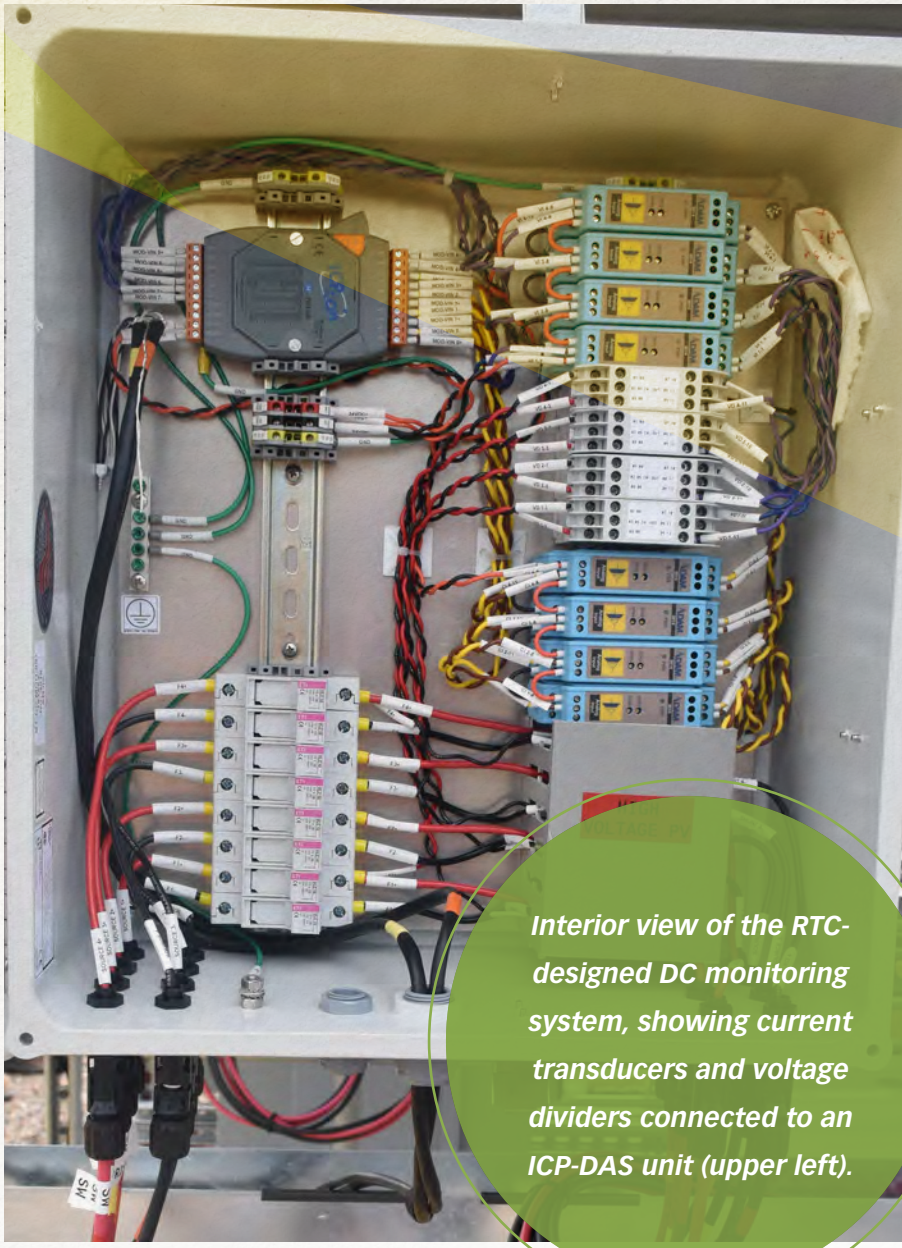
The RTCs have pushed to develop low-cost solutions to PV system monitoring without sacrificing data accuracy and quality. Two specific innovations were launched in 2016.

The first was the development of open source software that runs on low-cost Raspberry Pi microcomputers, allowing these devices to replace a traditional datalogger. This software enables the Raspberry Pi to send and receive MODBUS commands, store data in a local database, and transmit this information to a central database. [1]

The second innovation was the development of a low-cost, automated, string-level IV tracer that can be connected to as many as 32 strings and automatically disconnects a string from the inverter, performs an IV trace, then reestablishes the connection. This process only takes a couple of seconds and the inverter can continue to operate with only a momentary disturbance to the power output of the system. The hardware (140A Series II) is designed and built by Pordis LLC in Austin, TX according to technical requirements defined by Sandia National Laboratories.[2] The units are being used to monitor several systems at the RTCs.

1 Jones, C. B., M. Martinez-Ramon, B. H. King, C. Carmignani and J. Stein (2016). Wondering what to blame? Turn PV performance assessments into maintenance action items through the deployment of learning algorithms embedded in a Raspberry Pi device. 43rd IEEE Photovoltaic Specialist Conference. Portland, OR.

2 Jones, C. B., M. Martınez-Ramonz, R. Smith, C. K. Carmignani, O. Lavrova and J. S. Stein (2016). Automatic Fault Classification of Photovoltaic Strings Based on an In-Situ IV Characterization System and a Gaussian Process Algorithm. 43rd IEEE Photovoltaic Specialist Conference. Portland, OR.



Interior view of the RTC-designed DC monitoring system, showing current transducers and voltage dividers connected to an ICP-DAS unit (upper left).

A VALUED NATIONAL RESOURCE

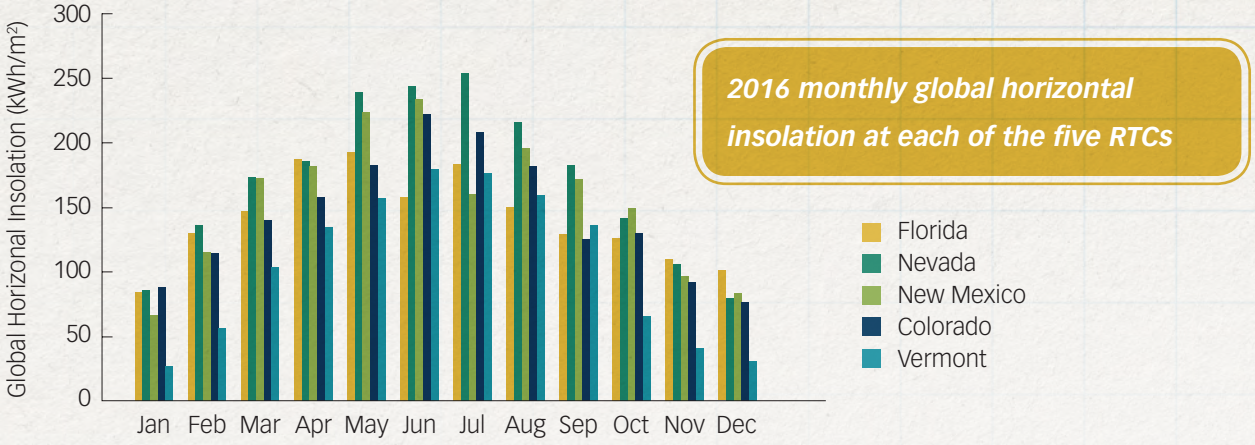
Industry partners have frequently provided feedback on the value of the RTC program, pointing to the importance of having access to the technical excellence and expertise at the national labs, to the exacting infrastructure at each RTC site that allows for accurate inter-site comparisons of performance and to the high-fidelity meteorological and performance data generated at each RTC site.

Some partners agree to have RTC results shared publically. For example, Prism Solar, a US manufacturer of bifacial PV modules and an RTC partner since 2014, obtained valuable information from their first RTC system installed in New Mexico and allowed the RTC team to publish the results in a report in 2016.[3]

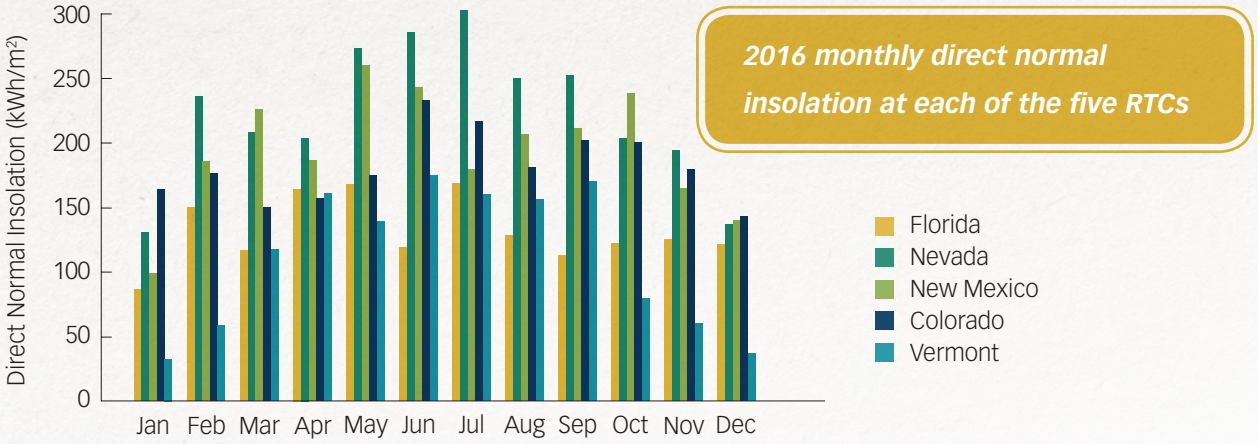
3 Lave, M., J. S. Stein and L. Burnham (2016). Performance Results for the Prism Solar Installation at the New Mexico Regional Test Center: Field Data from February 15 - August 15, 2016. Albuquerque, NM, Sandia National Laboratories. SAND2016-9253.

CLIMATIC VARIATION ACROSS THE RTCS

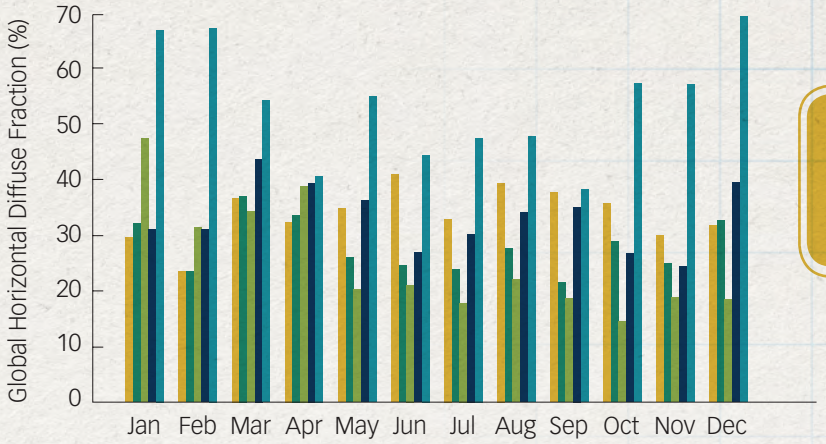
The five RTC sites represent a wide range in climatic conditions. This variation provides industry unprecedented access to multiple R&D sites, where PV technologies are exposed to different environmental conditions and stresses and performance and reliability is monitored. Nevada and New Mexico have the highest irradiance, Vermont is cold and humid, Colorado is cold and dry, Florida is hot and humid.



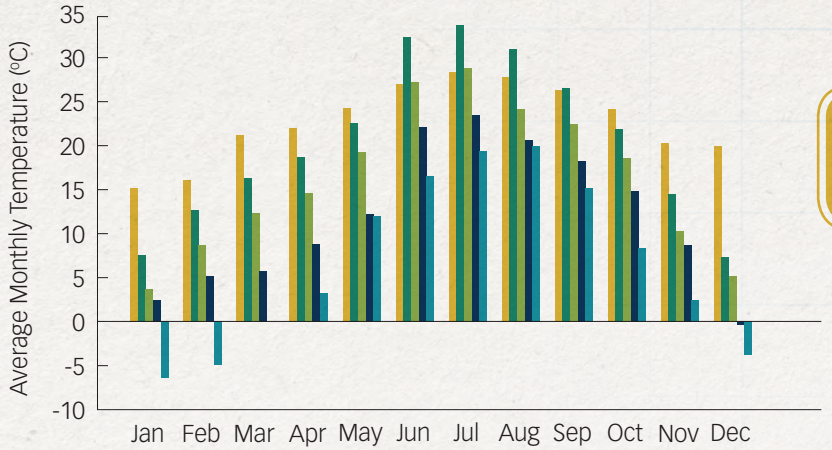
2016 monthly global horizontal insolation at each of the five RTCs



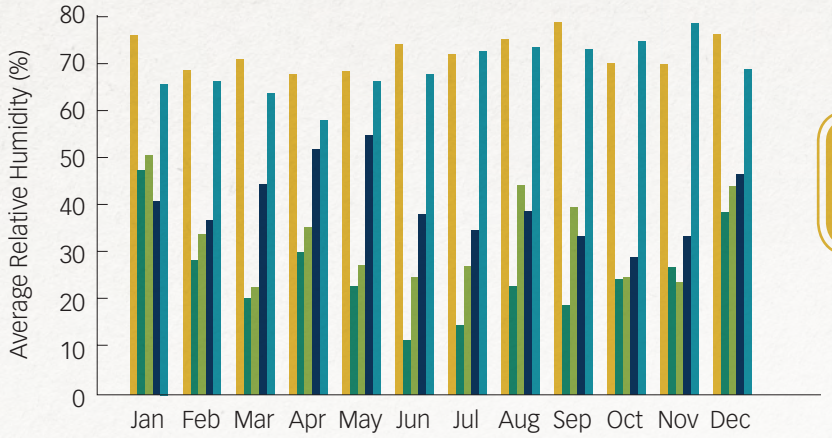
2016 monthly direct normal insolation at each of the five RTCs



2016 monthly average global horizontal diffuse fraction at each of the four Sandia managed RTCs



2016 monthly average air temperature at each of the five RTCs



2016 monthly average relative humidity at each of the five RTCs

COMMON INFRASTRUCTURE

Each RTC has a similar electrical infrastructure with a three=phase 480V grid tie. Single-phase 240 or 208V connections can be made available by either connecting to an onsite transformer or to a stepdown transformer specific to the system being installed.

Each site also has a mono-crystalline PV reference, or "Baseline" system against which the performance of other systems can be compared, and a weather station dedicated to the RTC program that has an identical base set of instrumentation. Additional site-specific instrumentation includes a spectrometer in NM, a spectral radiometer in NV, and soiling stations in NM, FL and VT to measure the accumulation of particulates on the surface of modules set at different tilt angles. A snow station will be installed in VT during 2017.

DATA AVAILABILITY AND SECURITY

While the data generated from partner systems is confidential and protected, data from RTC weather stations and from the baseline PV systems owned by the RTCs are available for public download. In 2017, the RTCs plan to release a new website, which will include data download features. Until then, data is available from the PVDAQ application: http://maps.nrel.gov/pvdaq.

Soiling measurement station at the VT RTC. Identical stations are installed at the NM, VT and FL RTCs.

While the infrastructures of the RTCs are virtually the same, the sites themselves vary in terms of size, layout, topography and capacity.

NEW MEXICO

System	Technology	Size (kW)
Existing PV Installations		
Stion	CIGS framed and frameless	12.32
Baseline	Suniva c-Si (mono)	6.48
Maxim	Smart PV modules	40
Prism Solar	Bifacial (monofacial for reference)	9.6
SunPower	Module prototype comparison	7.4
SunPower P-Series	c-Si shingled cells	6.9
Solar City	mono and bifacial modules	8
SolarWorld	mono and bifacial modules	8.7
PV Lifetime (Trina)	standard poly-Si modules	14.6
PV Lifetime (Jinko)	standard poly-Si modules	14.6
PV Lifetime (SolarWorld)	c-Si modules and microinverters	5.1
Total Site Power Rating		*133.7*

Other Installations

Soiling station	Optical transmittance measurements made at different tilt angles
Pordis	Thermocouple adhesion study
Outdoor spectrometer	Eco WISER spectrometers (350-1100 nm & 900- 1700nm)

2016 NM RTC Partner Inventory

The New Mexico RTC is located at the Photovoltaic Systems Evaluation Laboratory (PSEL), which is part of Sandia National Laboratories in Albuquerque. NM. The site has ample ground mount racking at 35˚ tilt. Planned electrical upgrades and site optimization in 2017 will provide capacity to deploy about 400kW of additional PV systems. The expanded capacity will be dedicated to future RTC deployment and other outdoor PV R&D activities. The site has two dual-axis trackers used for module characterization, a Spire 4600 flash simulator, EL and IR imaging, and an Atonometrics continuous solar simulator and light soak chamber among many other capabilities.

Aerial views of the New Mexico RTC.

FLORIDA

The Florida RTC is located at the Florida Solar Energy Center (FSEC) in Cocoa, FL and managed by the University of Central Florida. The site has ample ground mount racking at latitude tilt (~28.5˚) for additional systems. FSEC has several flash simulators, including a Spire 4600, EL and IR imaging, as well as numerous other analytic instrumentation.

PV systems at the Florida RTC.

System	Technology	Size (kW)
Existing PV Installations		
Heliovolt	CIGS frameless modules	5
Stion	CIGS framed and frameless	12.32
Baseline	Suniva c-Si (mono)	6.48
Maxim	Smart PV modules	40
Total Site Power Rating		*63.8*
Planned Installations (2017)		
SunPower P-Series	c-Si shingled cells	6.9
Solar City	mono and bifacial modules	8
SolarWorld	mono and bifacial modules	8.7
PV Lifetime (Trina)	standard poly-Si modules	14.6
PV Lifetime (Jinko)	*standard poly-Si modules*	*14.6*

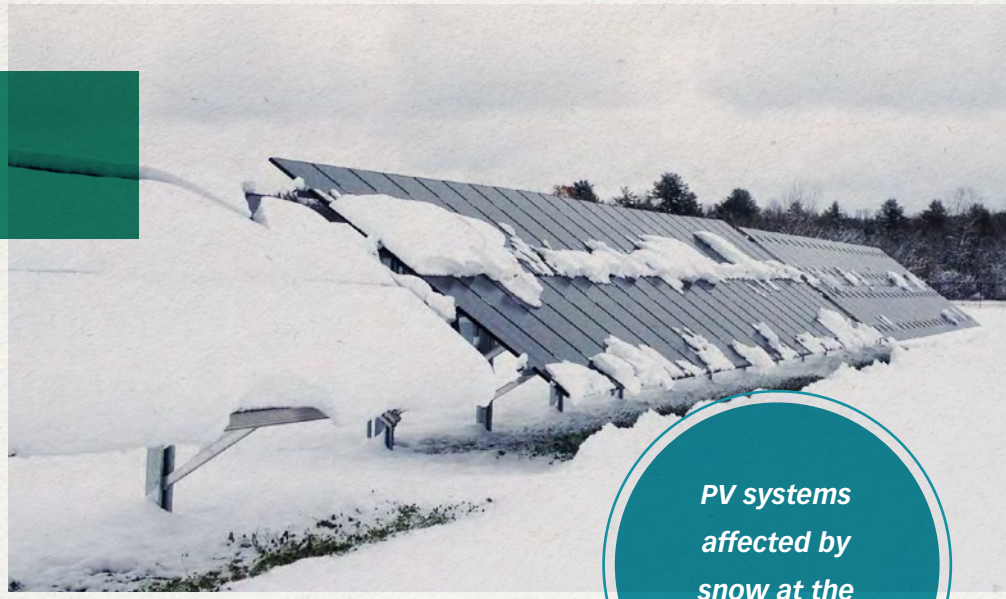
Other Installations	
Soiling station	Optical transmittance measurements made at different tilt angles
Pordis	Thermocouple adhesion study

2016 FL RTC Partner Inventory

VERMONT

System	Technology	Size (kW)
Existing PV Installations		
Stion	CIGS framed and frameless	12.32
Baseline	Suniva c-Si (mono)	6.48
60 kW	SolarWorld c-Si (mono)	60
Norwich Technologies / SolarWorld / Chilicon Solar	EZ-PV rooftop system	5.25
MiaSole -- PVMC	CIGS fixed tilt	2.88
MiaSole -- PVMC	CIGS single-axis tracker	2.88
Global Solar -- PVMC	CIGS	4.38
SoloPower – PVMC	CIGS	3.38
Solar Frontier – PVMC	CIGS	3.33
Prism Solar	Bifacial (monofacial for reference)	9.6
SunPower P-Series	c-Si shingled cells	6.9
Solar City	mono and bifacial modules	9.5
SolarWorld	mono and bifacial modules	8.7
All Earth Renewables	two-axis trackers for bifacial modules	13.9
Total Site Power Rating		*149.48*
Other Installations		
Renewable NRG	Solar resource measurement system	
Soiling station	Optical transmittance measurements made at different tilt angles	
Snow station	Modules at different tilt angles to monitor the effect of snow on PV power output	
Pordis	Thermocouple adhesion study	

2016 VT RTC System Summary



PV systems affected by snow at the Vermont RTC.

The Vermont RTC is located in Williston, VT on land owned and managed by GlobalFoundries. The fenced four-acre site has grid capacity for 300 kW of PV systems connected to 480V 3-phase AC. In addition to having pre-installed conduit and junction boxes to facilitate installations, the site has a recloser to allow for the installation of non-UL-listed equipment. An on-site equipment shed houses the site server, electrical and PV panels, and also serves as a storage/staging facility for monitoring equipment, modules, etc. In 2017, the Vermont site will host a snow station onsite that will allow the team to study the impacts of module tilt angle and height above ground on snow accumulation. The site does not have onsite flash test capability but can perform outdoor module and string-level IV traces.

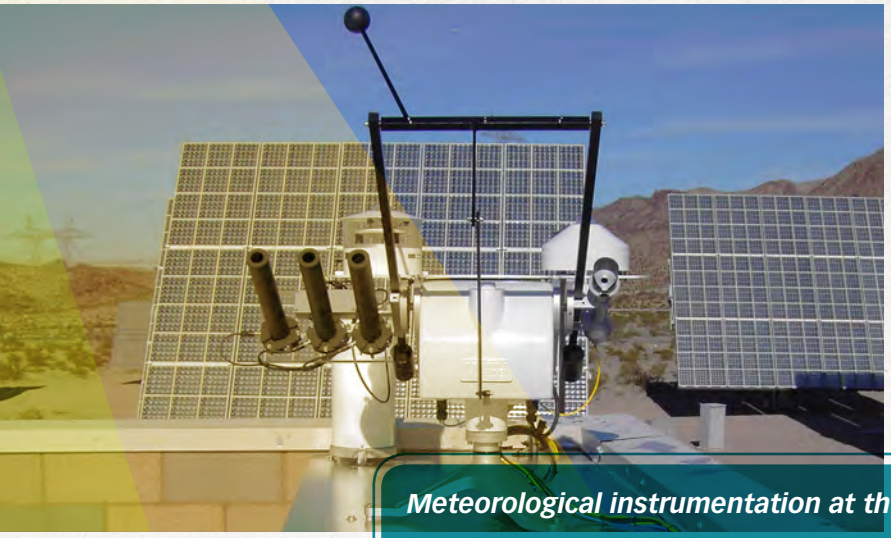
Baseline system at the NV RTC, with irradiance sensors mounted in the plane-of-array

NEVADA

The Nevada RTC is located in the city of Henderson, on land occupied by the River Mountains Water Treatment Facility, which is operated by the Southern Nevada Water Authority (SNWA). The site does not have onsite flash test capability but can perform outdoor module and string-level IV traces.

System	Technology	Size (kW)
Existing PV Installations		
Soitec	CPV system on three trackers	84
Baseline	Suniva c-Si (mono)	6
Prism Solar	Bifacial (monofacial for reference)	9.6
Total Site Power Rating		*84*
Future Installations (2017)		
Solar City	mono and bifacial modules	9.5
SolarWorld	mono and bifacial modules	8.7
Other Installations		
Pordis	Thermocouple adhesion study	

2016 NV RTC System Summary



Meteorological instrumentation at the NV RTC, with the Black Photon spectral radiometer visible to the left.

COLORADO

The Colorado RTC is located at the National Renewable Energy Laboratory main (South Table Mountain) campus in Golden, CO near Denver. This site has access to the module and system characterization expertise and equipment located at NREL.

System	Technology	Size (kW)
Existing PV Installations		
Baseline	Suniva c-Si (mono)	2.8
SunPower	Module prototype comparison	7.2
SunPower P-Series	c-Si shingled cells	6.9
Solar City	mono and bifacial modules	10.3
SolarWorld	mono and bifacial modules	8.3
Soitec	CPV modules	0.2
PV Lifetime (Trina)	standard poly-Si modules	14.6
PV Lifetime (Jinko)	standard poly-Si modules	14.6
Trina Solar	Potential induced degradation study	11.1
Total Site Power Rating		*99.6*
Other Installations		
Soiling station	Optical transmittance measurements made at different tilt angles	
Stion edge seal material evaluation		

2016 CO RTC System Summary

RTC INDUSTRY PARTNERS

More than 20 companies are now RTC partners, and all of them have products that showcase technical advances, such as higher efficiency or better value, and all offer the promise of a future increasingly defined by low-cost and reliable solar energy.

Project	Company/partner	Tech Types	NM	CO	FL	NV	VT
RTC	Heliovolt (out of business)	1	DC	DC	O		
RTC	Stion	2	O	O	O		O
RTC	Suniva	1	O	O	O	O	O
RTC	Maxim	3	O	DC	O		
RTC	SunPower (Bifi)	4	O	O			
RTC	SunPower (P-Series)	1	O		I		I
RTC	Solar City	4	O	O	I	I	I
RTC	SolarWorld	4	O	O	I	I	O
RTC	Soitec (not in CPV anymore)	1		O		O	
RTC	Prism	2	O	O		O	O
RTC	ENKI	3	O		O		
RTC	All Earth Renewables	3					O
RTC	Renewable NRG	1					O
RTC	Norwich/Chilicon/ SolarWorld	3					O
RTC	Ten K Solar	1		O			
PV Lifetime	Trina	1	O	O	I		
PV Lifetime	Jinko Solar	1	O	O	I		
PV Lifetime	SolarWorld/Enphase	1	O				
PVMC	Miasole	1					O
PVMC	Solar Frontier	1					O
PVMC	Global Solar	1					O
PVMC	Solopower	2					O
	Totals	*42*					

List of RTC Partners

O = Operational, I = Installations in progress, DC = Decommissioned.

PV LIFETIME PROJECT

Funded separately by the DOE, the PV Lifetime project is one the tenants of the RTC program. It provides an opportunity to generate PV performance data for a variety of commercial technologies that represent significant market share in the US. Data from this project will be placed in the public domain. Started in 2016, the PV Lifetime Project is measuring and communicating module degradation profiles over time, including the uncertainty and any differentiation between hardware types. Outdoor energy monitoring in different climates is supplemented with regular characterization under repeatable laboratory conditions indoors. The focus will be on the PV module, as well as other hardware components (junction boxes, bypass diodes, module-level electronics) attached to it. Hardware is being installed at the DOE Regional Test Centers and monitored on an ongoing basis. Performance data will be made available to the public online in 2017. The data is expected to enable an increase in the accuracy and precision of degradation profiles calculated for representative PV hardware installed in the U.S.

Trina Solar PV Lifetime array at the New Mexico RTC site.

By the end of 2016, five PV Lifetime systems were installed at the NM and CO RTCs. Additional systems are planned for future years. When fully deployed, the PV Lifetime project is projected to have ~45 systems deployed across three locations.

Jinko Solar PV Lifetime array at Colorado RTC site.

THE RTC PROGRAM: A CATALYST FOR GROWTH

The RTCs are an important part of the US strategy to become technology leaders in the solar PV industry. Solar energy has recently become the most economical and fastest growing form of new electrical generation in the US, with US solar jobs growing by almost 25% in 2016. To maintain this growth, it is necessary to ensure that current and new solar technologies that come to market are robust to varying environmental conditions and climates and predictably produce the amount of energy projected for their service lifetimes. The RTCs serve an important role by providing expert evaluations in diverse climates to help US industry produce the highest quality solar PV technology for their customers.