October/November 2011

PV Installation Hazards | Structural Blocking

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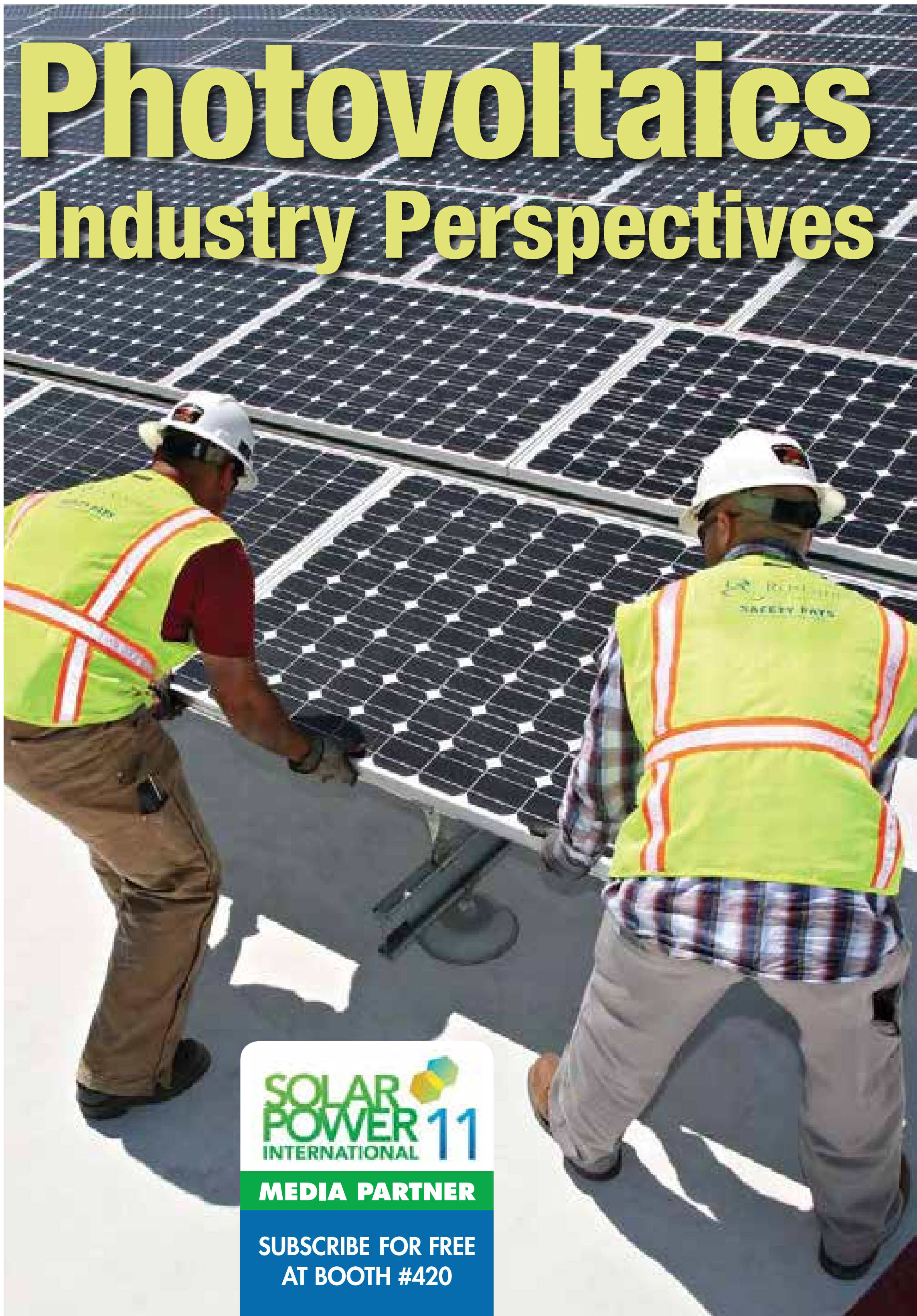

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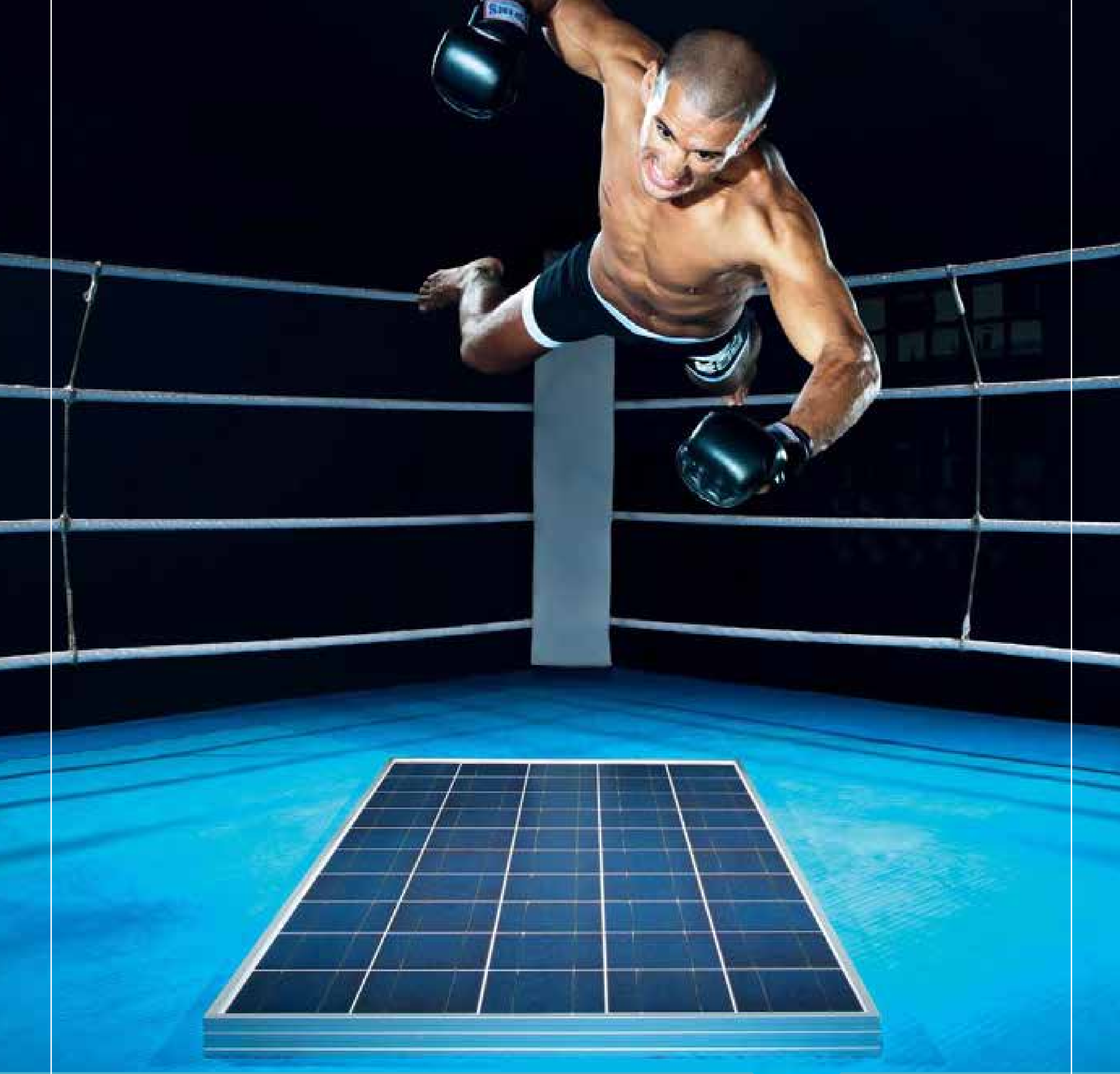

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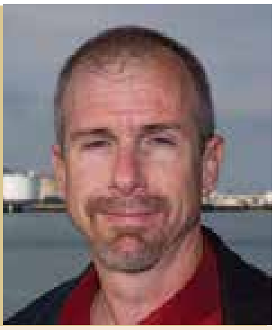
ON THE COVER **The 1.12 MW PV system located at the Mineta San Jose International Airport was designed by iPower and installed by Rosendin Electric. The system utilizes 4,680 Canadian Solar modules, Unirac ISYS roof mounts and two Advanced Energy Solaron 500E inverters.**

Photo Courtesy Rosendin Electric

Contributors

Experience + Expertise

Bill Brooks is a registered professional engineer in both North Carolina and California. He has written widely used technical manuals for the PV industry and consulted on a variety of topics—including performance, troubleshooting and training. Since 1992 he has focused on the analysis and testing of PV systems for utility-interconnected applications. His experience includes work on the technical review committees for the *NEC* and the Institute of Electrical and Electronic Engineers (IEEE).

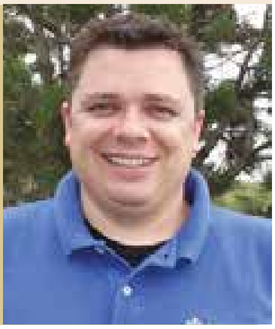


Rebekah Hren is a licensed electrical contractor, NABCEP Certified Solar PV Installer and ISPQ Certified PV Instructor for Solar Energy International. She has a wide range of solar experience, from living off-grid for many years, to installing PV and solar hot water systems, to designing utility-scale PV arrays with North Carolina–based developer O_2energies. Hren writes technical articles for PV trade magazines and has co-authored two renewable energy books: *A Solar Buyer's Guide* and *The Carbon-Free Home.*

Kyra Moore began her career in the renewable energy field in 2008 when she joined Southern Energy Management (SEM) as a solar technician and sales representative. She now serves as one of SEM's commercial solar system designers. She holds NABCEP certifications in PV installation and PV technical sales. Moore is currently enrolled in the graduate Renewable Electric Energy Systems Program at North Carolina State University, and she instructs classes on PV for the NC State Solar Center.

Karl Riedlinger is the chairman of SEIA's Installer Safety taskforce and the director of field engineering at SolarCity, where he is responsible for managing installation procedures, installer training and certification programs, and installation quality control. Prior to joining SolarCity, Riedlinger was a construction manager for large commercial solar installations at Powerlight. Riedlinger holds a BS in mechanical engineering, is a California licensed general electrician and is NABCEP certified in PV installation and PV technical sales.

Ryan M. Smith has been a senior engineer at the National Renewable Energy Laboratory (NREL) since 2009, where he focuses on long-term PV module reliability and the measurement quality of PV monitoring systems. Prior to NREL, he worked as a process metrologist at Advanced Micro Devices and at Spansion. Smith holds BS and MS degrees in materials science and engineering from the University of Michigan and Certified Quality Engineer and Certified Manager of Quality credentials from the American Society for Quality.



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QA Quality Assurance

PV Installation Hazards and Mitigation

In an increasingly competitive PV marketplace, project managers and installation forepersons regularly face tight project budgets and narrow installation time frames. Considering these pressures, developing safety procedures, scheduling the associated training and then implementing and enforcing the programs on the jobsite may seem unnecessarily burdensome. However, making worker safety a priority is not optional. It is imperative for your business and for the PV industry as a whole. Integration teams need to clearly understand the difference between what might be considered common sense approaches that provide a minimum level of safety on-site and being in compliance with the law. Safety programs should always be conscientiously developed to meet the requirements of the latter.

Professionals tasked with site safety program development and implementation must thoroughly research the laws and regulations of the Occupational Health and Safety Administration (OSHA) to determine which are applicable to the work being performed (see "Implementing a Successful Safety Program," pp 108–130). You must not only understand, communicate and enforce these regulations, you must also be certain your employees adhere to them to keep themselves and their coworkers safe. While the full breadth of common hazards PV installers face cannot be sufficiently detailed in a single article, here I present several top-level concerns that you should consider and address. Future *SolarPro* articles will delve into some of the topics introduced here in greater detail. My intent is to make you aware of the laws that govern the work you do and to motivate you to take the steps necessary to increase the overall safety of your installation teams.

Fall Hazards

While falls are obvious hazards PV installers face, standards dealing with fall protection are among the most commonly misunderstood and violated OSHA regulations. Low-slope roofs and pitched roofs present different challenges. The applicable solutions depend on several variables, including regional OSHA fall protection regulations, the pitch of the roof, the size and location of the work area, the height of the roof, the roofing material and the presence of additional openings on the surface, such as skylights. You must also consider the load capability of the roof, the number of workers present, the weight of the workers, the workers' level of fall-protection competence, the availability and location of qualified anchoring points, parapet heights and many other details.

Navigating these variables to execute the proper fall protection system requires planning, training and a competent person to design and implement the fall protection system. According to OSHA, a *competent person* is defined as "one who is capable of identifying existing and predictable hazards in the surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them." [Standards 29 CFR, 1926.32(f)]. OSHA's website includes the following additional details: "By way CONTINUED ON PAGE 18

Fall hazards Fall protection standards are among the most commonly misunderstood and violated OSHA regulations. Low-slope roofs and pitched roofs present different challenges, and the applicable solutions depend on several variables, including regional OSHA fall protection regulations.

Courtesy REC Solar

of training and/or experience, a competent person is knowledgeable of applicable standards, is capable of identifying workplace hazards relating to the specific operation, and has the authority to correct them. Some standards add additional specific requirements which must be met by the competent person." This somewhat vague description leaves the responsibility of qualifying a person as competent to the discretion of the company, without defining any criteria for testing or external certification.

More complicated fall protection systems, such as horizontal lifelines, require the designer to be a *qualified person*—who, as defined by OSHA, is a person with a higher level of experience and expertise than a competent person. OSHA defines a qualified person as "one who, by possession of a recognized degree, certificate, or professional standing, or who by extensive knowledge, training, and experience, has successfully demonstrated his ability to solve or resolve problems relating to the subject matter, the work, or the project." Numerous companies across the country offer fall-protection courses designed to train individuals to meet the qualified person–level requirements.

According to OSHA's hierarchy of control, the first option to consider in a fall protection system should be to eliminate the hazard. For low-slope roofs with low parapets, this is best accomplished with guard rails to physically prevent workers from easily accessing locations that present a fall hazard. The use of traffic cones and caution tape as a low-cost warning line system is a common practice. However, this method satisfies neither OSHA's hierarchy of control nor the formal requirements of a warning line system and could have serious consequences if a worker is hurt. Guardrails are a higher level of protection and should be used whenever possible. A properly designed warning line system that complies with the provisions in OSHA Standard 29 CFR, 1926 Subpart M, 1926.502(f) is a possible alternative if guardrails cannot be utilized.

The roof edges are obvious fall hazards, but any openings (such as skylights) present significant hazards. Some skylight models are fall protection rated, meaning at the time of their manufacture they met rating criteria for impact resistance. However, the skylight material may have degraded over time. In addition, the impact requirements for skylights may change. It is prudent not to trust the ratings, with the possible exception of very recent installations. When in doubt, consult with the skylight manufacturer or a professional who is familiar with the impact rating on the skylight product.

Guardrail systems are difficult to implement on pitched roofs, so fall restraint, fall arrest or work positioning systems are common. A fall restraint system is a higher form of protection and more preferable than a fall arrest system because it keeps a worker from encountering a fall hazard in the first place. A fall arrest system may allow a worker to fall but will stop the fall and limit any injury. On very steep roofs or vertical facades, you may need to use a work positioning system, such as those used on wind turbines where the installer is constantly supported by ropes. Additional systems, such as safety monitoring systems, horizontal lifelines, scaffolding and safety nets, are not as common in applications like residential retrofit PV installations.

It is important to stress that competent or qualified persons must design and install a fall protection system and train all employees on its proper use. Workers should also receive training on fall rescue methods and have a documented rescue plan for each jobsite. If there is a fall, the crucial minutes spent figuring out what to do can mean life or death for an injured worker. Fall rescue planning should be part of the overall site safety plan that must be communicated before work begins.

Shawn Schreiner

Lock out/tag out To prevent installers and facility personnel from inadvertently re-energizing circuits during system installation or scheduled maintenance, documented lock out/tag out procedures should be diligently followed.

Electrical Hazards

Electricity poses hazards, both in the form of electrocution and arc flash. Every effort should be made to de-energize circuits before performing work on them. While this may be an inconvenience for the customer, worker protection is paramount. Removing the electrical hazard reduces the need for cumbersome personal protective equipment (PPE), so the work can progress more efficiently and with greater safety. Once the circuits are de-energized, a foreperson should implement a lock out/tag out system to prevent installers and facility personnel from inadvertently re-energizing the circuits. De-energizing can be as simple as locking out a breaker or disconnect, or it may require a utility shutdown at the service entrance. The point of connection and the layout of the electrical hardware dictate how far upstream power should be disconnected to prevent access to live parts.

When testing or troubleshooting must take place on live circuits, workers must employ the appropriate PPE in accordance with the electrical energy present. The required protective equipment ranges from properly rated insulated gloves to a properly rated arc-flash suit, depending on the hazard. The national Fire Protection Association's "Standard for Electrical Safety in the Workplace" (NFPA 70E) is the best resource for understanding the proper mitigation of electrical hazards.

Material Handling

Many worker injuries—such as cuts, scrapes, bruises, burns, muscle pulls, sprains, strains and broken bones—can be attributed to improper material handling. Overexertion, slips, trips, falls or mishandling of materials can result in soft tissue injuries that can lead to lifelong problems for the worker. Workers need to slow down and take a moment to properly prepare to perform an activity, ask for help when needed and use safe material handling procedures, tools and equipment. Crews are too often hurried and under pressure, which can lead to mistakes and potentially serious injuries. As with performing sports activities, stretching before beginning physical installation work can prevent soft tissue damage. The body responds better to physical labor after an adequate warm-up. In addition, proper PPE—including safety glasses, properly rated gloves, hearing protection, hardhats, kneepads and properly rated shoes—can provide protection from specific jobsite hazards.

One area where the industry is receiving increased support from equipment manufacturers is with improved methods of PV module transport to the roof. On smaller jobs, it has been standard practice for workers to carry modules up to the roof while ascending a ladder. This is a very unsafe practice and a violation of OSHA's ladder safety rule of maintaining three points of contact while on a ladder. Several manufacturers now provide portable gas- or electric-powered ladderlike lifting devices designed for PV modules, similar to equipment that roofers have used for years. While the upfront equipment expense may seem high, it is hard to ignore the value these products present. They substantially reduce the risk to workers who must transport materials to the roof on smaller projects where cranes or reach lifts are not economically justifiable.

Respiratory Protection

The presence of dust and vapors makes respiratory protection necessary. This can range from a simple fabric mask to a self-contained breathing apparatus. PV installers are commonly exposed to dust or silica from cutting or drilling roof tiles, sheetrock and insulation fibers present in attics. Organic vapors from mastics, cleaning solutions, adhesives and paint also make respiratory protection necessary. In older residences, workers may be exposed to lead and asbestos. You should perform proper testing if you suspect these materials may be present and make certain the crew utilizes appropriate care. Before wearing any respiratory protection beyond a simple dust mask, employees should receive appropriate training, undergo respirator fit testing and possibly have a medical evaluation (Standard CFR 1926.103).

Environmental Exposure

Installers spend much of their time working in the sun for extended periods, often in extremely hot temperatures. Heat illness is a very serious and widespread condition that can come on unexpectedly. You should take steps to mitigate heat-related illnesses, such as heat exhaustion and heat cramps. The following information is adapted from OSHA's "Protecting Workers from Heat Stress" (OSHA 3154) publication that identifies heat-related risk factors, symptoms and steps to prevent related injuries.

Risk factors for heat illness:

- High temperature and humidity
- Direct sun exposure
- No breeze or wind
- Low liquid intake
- Previous heat illnesses
- Heavy physical labor
- Waterproof clothing
- Recent exposure to hot workplaces
- Working while sick, overly tired or hung over

Symptoms of heat exhaustion:

- Headache
- Dizziness
- Fainting
- Weakness
- Wet skin
- Irritability or confusion
- Thirst, nausea or vomiting

Symptoms of heat stroke:

- Confusion
- Collapse
- Loss of consciousness
- Seizures
- No sweating

Prevention measures. To prevent heat-related illness, provide training about the hazards and how to prevent them. Workers need to know how to protect themselves and fellow installers by knowing the signs and symptoms of heat illness, monitoring themselves and using a buddy system.

Offer cool water to workers from large water jugs that are convenient to the work area. Each crewmember should drink at least one pint of water per hour, so be sure an adequate supply is provided. Workers must drink water often and before they feel thirsty, and they should CONTINUED ON PAGE 22

avoid beverages containing alcohol or caffeine. Schedule frequent rest periods with water breaks in shaded or air-conditioned areas.

Workers should wear lightweight, light-colored, loose-fitting clothes. Routinely check workers who are at risk of heat stress due to heavy protective clothing. Consider protective clothing that is designed with cooling in mind.

Risk factors. Workers who are in poor physical condition, who suffer from high blood pressure or diabetes, or who have a cold or the flu are at greater risk for heat-related illnesses. Pregnancy also increases sensitivity to heat. Some medications can increase a crewmember's personal risk: Workers who are under medical treatment should check with their healthcare provider and get approval for working in exposed, high temperature environments.

First aid for heat illnesses. If a worker is seriously affected by the heat, crewmembers should call a supervisor for help. If the supervisor is not available, they should call 911. Have them move the worker to a cooler area, and make sure someone stays with the affected worker until help arrives. Remove the worker's outer clothing and provide cool drinking water. Fan and mist the worker with water and apply ice via ice bags or iced towels. Someone who is not alert or seems confused may be suffering from heat stroke: Call 911 immediately.

Vehicle Safety

According to the US Department of Labor, motor vehicle accidents are the leading cause of workplace fatalities. Transportation becomes a worker safety issue when employees are on the clock driving to and from jobsites or running errands for materials. Workers should be required to use an excess of caution while driving, avoid distractions and, of course, obey the laws of the road. While safety is always the priority, you should direct your employees to be sensitive to the fact that what they may be comfortable doing in their own private vehicles may not be appropriate in their work vehicles. Since most vehicles prominently display the company name and contact information, things like blasting the radio and driving aggressively can draw the attention of fellow motorists, who then associate your company with this behavior.

Karl Riedlinger / SolarCity / San Mateo, CA / solarcity.com

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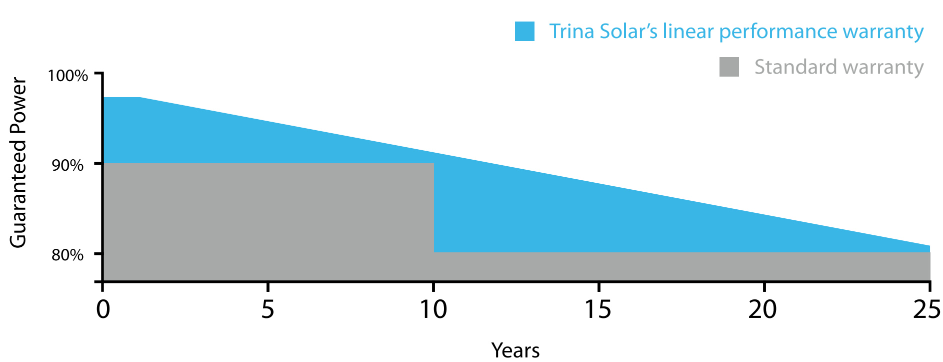

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Internal Wood Blocking for Roof-Mounted PV

For residential pitched-roof applications, array mounts are typically secured to the roofing system by one of two approaches. The first method utilizes lag screws to attach the array racking to the roof system's trusses or rafters. The second method is to fasten the mounts directly to the roof's sheathing. From a structural loading standpoint, a third method should also be considered: attaching array mounts to internal blocking that is secured to the trusses or rafters.

Here I discuss engineering obstacles that installers may face when common attachment methods are specified, and I recommend materials and techniques for use with internal wood blocking. If you frequently use internal blocking, it may be prudent to have your engineer develop standard drawings that include tabulated tables based on fastener and bracket data to minimize ongoing costs.

Common Attachment Issues

Integrators may be confronted by a variety of issues related to direct attachment to structural roofing members such as trusses or rafters. Paragraph R802.10.4 of the 2009 *International Residential Code* states, "Alterations resulting in the addition of load that exceeds the design load for the truss shall not be permitted without verification that the truss is capable of supporting such additional loading." Some AHJs interpret this to mean that attaching a PV array to trusses is an alteration. They rightly conclude that structural members with mounts attached support a greater load. This is because the mounting system changes the way the load is distributed on the roof. For example, in the case of snow loading, PV arrays change what was formerly an even load distributed over the entire roof system to a significantly larger load concentrated at the array racking attachment points.

Potential loading issues are compounded when trusses or rafters are skipped in an effort to minimize roof penetrations. In addition, you forfeit the ability to use the "15% repetitive member factor" that is normally allowed in structural member calculations. This allowance is applicable when three parallel structural members share the load and they are spaced 24 inches or less apart from each other. The factor allows additional calculated capacity, primarily because there is a low probability that all three members will be the weakest strength for the type of wood present, and that all will have defects in the same location. As illustrated in the photo below, maximizing rail spans to minimize penetration and attachment points creates more significant point loading and can complicate engineering requirements.

Paragraph R802.10.4 of the 2009 *International Residential Code* also states, "Truss members shall not be cut, notched, drilled, spliced or altered in any way without the approval of a registered design professional." This requirement is problematic. Unfortunately, trusses are now typically designed with proprietary software controlled by a small number of truss manufacturing firms. In fact, ANSI/TPI-1, "National Design Standard for Metal Plate Connected Wood Truss Construction," no longer provides the equations required to accurately calculate truss loads. Consequently, without a ready calculation method to support them, structural engineers occasionally refuse to allow attachment to the trusses, leaving PV system installers with limited options.

Installation methods that rely solely on attaching racking to plywood or other roof sheathing types present their own set of potential issues and can be questionable CONTINUED ON PAGE 26

Courtesy Shelly Engineering

Overbuilt A building department required an engineering evaluation for this residential building, which resulted in these sistered rafters. Internal blocking would likely have been a more cost-effective approach.

practices. This is especially true in locations with strong wind loads, or if the array design specifies widely spaced mounting feet or long mounting rails. This is not to say that this method cannot be used, but you should proceed with caution. Plywood and other forms of engineered wood sheathing are made up of highly variable composite materials. The nails that secure the sheathing to the structural members are already under shear loading in high wind conditions. Shear failure often results in nail pullout, and additional loads associated with PV arrays should be mitigated. For example, a PV array mount attached to the corner of a plywood sheet could easily overload the nails.

You must also consider thermal expansion and contraction. Thermal cycling of rail-mount systems stresses the fastener joint due to daily and yearly swings in temperature. Plywood is especially susceptible to the effects of thermal expansion, as the fastener rotates in a relatively shallow hole. I have done tests showing that elongated holes and reduced pullout strength are possible, if not common. If you must mount a PV system directly to wood sheathing, it is best to use mounts that allow for multiple fasteners to reduce possible rotation, use plenty of racking attachment points and, most importantly, keep the rail lengths short to minimize the impact of thermal cycling on the attachments.

Considering these potential issues, using internal blocking attached to the trusses or rafters may be optimal for some projects. I describe three distinct methods: blocking between structural members; blocking attached to structural members; and repair blocking for structural members damaged by misplaced attachments that left empty holes in the trusses or rafters.

Courtesy Shelly Engineering

Better fit This roof mockup demonstrates that 2-by-6-inch blocking does not fit between composition shingle roof nail rows, which tend to be spaced 5 inches apart. The dimensions of 4-by-4-inch blocking better match standard roof shingle nail patterns and reduce the number of nail ends that need to be cut.

Wood Blocking Between Structural Members

Internal blocking methods that facilitate array attachment do a better job of distributing loads over the entire roof system, and may well be your best design option for some projects. Staggering blocking between array rows also helps distribute the load and prevents too much stress at any one location.

While the structural benefits of attaching PV arrays to internal wood blocking are significant, the best method of installing the blocking is not widely understood. For example, the *NABCEP 2009 PV Study Guide* provided online at nabcep.org recommends laminating 2-by-6-inch members secured with two fasteners on each side of each board (see Paragraph 3.4.1). These installation details are somewhat vague, and a strength value cannot be assigned to this method of attachment. In addition, residential roofs made of composite roofing material usually have shingles installed in overlapping rows spaced approximately 5 inches apart. Nails for shingles are required to penetrate the plywood ¾ inch or extend through the sheathing. This means that a 2-by-6 is wider than the protruding nail spacing, requiring many nails to be cut to get the block flush against the underside of the sheathing. A better method is to use 4-by-4-inch blocking, attached with metal nailing angle plates. You still may need to cut an occasional nail to get the 4-by-4 blocking flush with the sheathing, but you will cut significantly fewer than if you used 2-by-6 blocking.

It is also important to note that toe-nailed wood joints should not be considered for structural loads, unless the nails are used in conjunction with an appropriately designed and tested metal connector. I evaluated several methods for securing 4-by-4 internal blocking using angle brackets from USP or Simpson Strong-Tie. These brackets are readily available at building materials CONTINUED ON PAGE 28

Courtesy Shelly Engineering (2)

Angle brackets The Simpson A21 Angle (shown here with 10d x 1.5-inch nails) is one recommended product, due to nail hole locations, chamfered corners and published structural loading data. Simpson specifies different values for use with either nails or structural screws.

centers. I prefer the Simpson angle products due to the nail hole locations and chamfered corners, so I show one in the photo to the left. However, the principles apply to other metal angle brackets.

As proof of code equivalence, most states require calculations from a paid, state-registered professional engineer, or data or installation instructions published by the equipment manufacturer. In the case of metal angle brackets, you can source data for engineering calculations from the manufacturer's catalog. Calculate the load capacities based on four angles, with all four acting at a time for wind and snow loading and only two acting at a time in shear. These calculations are conservative, as they ignore the load supported by the plywood, but using these recommended calculations is less costly than having an engineer calculate a larger capacity.

The following calculations are based on the Simpson-Strong Tie Catalog data for the A21 Angle for a rafter or truss using a wood type (SPF, SYP or DF-L) specified in the 2009 *International Residential Code* with the dimensions of 4 by 4 inches. In this example, the block has a wind uplift load capacity of 600 pounds, a snow load capacity of 375 pounds and a down-slope shear capacity of 270 pounds. Off-center loading reduces these values by up to 50%. If you know the woods used, you can calculate their specific load capacities. The particular values presented here cannot be used for permit justification, but they illustrate the minimum values that internal blocking can obtain.

Internal blocking components can be made up ahead of time on rainy days and brought to the site. Angles can be prenailed to slightly undercut 4-by-4

Load distribution A 4 x 4 secured to the trusses or rafters with four Simpson Strong-Tie A21 Angles and 10d x 1.5-inch nails is an excellent blocking method. This approach transfers snow loads to two structural members and reduces the number of required array attachment points. Blocking can be installed with a hammer or, better yet, a palm nailer.

QA

Courtesy Shelly Engineering

Side-applied A wood block nailed to the side of a rafter or truss can be used to secure a PV array mount. One advantage is that if the PV array is removed in the future, the removal does not weaken the roof system.

blocking prior to installation to reduce attic assembly time. The undercut should not exceed ¼ inch. Brackets with chamfered corners help prevent handling cuts. A palm nailer speeds up installation time, especially in tight spaces. Finally, blocking can be placed after a roof hole penetration is made to ensure correct row alignment.

Wood Blocking Attached to Structural Members

Wood blocking installed against structural members is not typically considered an alteration of the truss or rafter, because nailing to the side of the member does not remove or damage the high-stressed wood fibers on the upper surfaces of the truss or rafter. The blocking strength can be calculated based on shear values published in the *National Design Specification for Wood Construction.* These calculations tend to be conservative because the sheathing provides additional strength. You can obtain more strength by increasing the length of the blocking and number of nails or screws used. The withdrawal strength of the upper nails prevents block rotation due to off-center loading.

I suggest using this method when installing wood blocking against structural members: Secure four 10d common nails between 3/4 and 1 inch from the upper edge, but no closer than 1.5 inches from the cut ends of a 1-foot block. Use another two nails staggered along the bottom of the block. For this method, I calculate a wind uplift load capacity of 590 pounds, a snow load capacity of 420 pounds and a shear capacity of 370 pounds for the least dense structural wood (spruce, pine or fir) allowed for rafters in the 2009 *International Residential Code.* The total capacity is dependent on the array-mount attachment method as well.

Wood Blocking for Rafter or Truss Repair

You should also be aware of the effects of misplaced holes in structural members and the holes created by the possible removal of a PV array in the future. Lag screw attachments do not reduce the loaded strength of a rafter or truss because they can take a compressive load and the upper surface of these structural members are in compression. However, the empty holes they leave behind should they be removed do reduce the roof system's strength. This can be especially detrimental if a row of empty holes occurs near a plywood seam.

If you drill a hole in the wrong location or too close to the side of the structural member and an unused hole is created, modifying the method of wood blocking against structural members (as described earlier) can also be used as a repair procedure. Add a structural construction adhesive to the surfaces that bear against the sheathing and structural member before securing the block with nails. The additional adhesive bond allows transfer of the beam's compressive structural load around the empty hole that the nail alone cannot. Refer to the instructions for the adhesive to determine the amount required for the specified bond thickness (you may need to find these on the web). For your workers' health, I suggest using an adhesive that does not give off harmful fumes. Loctite's Power Grab Heavy Duty is a good option.

Metal plates marketed as "repair plates" should not be used for truss or rafter repair. First, the nails cannot take the shear load. Second, the overuse of nails allowed by the plates tends to shred the structural member. And third, there is no calculation data to support the use of metal plates in truss or rafter repair applications.

—Mark Shelly / Shelly Engineering / Jackson, NJ /shellyengineering.com


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SunLink Adds Utility-Scale Ground Mount

[San Rafael, CA] Widely known for its ballasted low-slope roof mounts, SunLink is introducing a new ground-mount solution for large commercial and utility-scale solar plants to its product portfolio. The Utility Scale Ground Mount includes fully integrated equipment grounding and wire management, is compatible with all module types and allows for tilt angles ranging from 15° to 30°. The design can handle changes in grade up to 12% and has built-in 3-inch vertical and 1-inch east-west/north-south adjustment, as well as +/-5° rotation adjustment to mitigate the impact of variations in site grade and post placement. The racking structure can be used with a variety of post options, including ground screws and driven piles (I-beam, pipe and custom), and it can facilitate preassembly of three or four module panels to increase installation efficiency. The Utility Scale Ground Mount carries a 20-year warranty and is ARRA and Ontario FIT compliant.

SunLink / 415.925.9650 / sunlink.com

AUO Solar Partners with SolarBridge

[Milpitas, CA and Austin, TX] Developed for the North American market, the recently announced AUO AC Unison product features a SolarBridge Pantheon microinverter preinstalled on a 250 W monocrystalline module manufactured by AUO Solar. While the solution is still one step away from a fully integrated micro/module product, the frame-attached inverter/module pairing will be listed as a complete assembly to meet UL 1741 requirements for ac modules. The AUO AC Unison PM250MA0 is expected to begin shipping in Q3 2011 and will be sold by AUO Solar through its network of distribution partners.

AUO Solar / 408.518.8800 / auosolar.com

SolarBridge Technologies / 877.848.0708 / solarbridgetech.com

Seaward Solar Offers PV Electrical Tester

[Tampa, FL] The Seaward Solar Installation PV100 is a multifunction electrical tester developed specifically for grid-connected PV array commissioning and troubleshooting. The PV100 connects directly to array wiring using the supplied MC4 or Sunclix connectors and performs a series of tests—ground continuity, insulation resistance, Voc, Isc and operating current. Data for up to nine strings can be stored in internal memory. An automatic comparison of voltage and current measurements between strings indicates any variation greater than 5%. The insulation resistance test can be run at voltages of 250 V, 500 V and 1,000 V.

Seaward Solar / 813.886.2775 / seawardsolar.com

OutBack Introduces Inverter/Charger

[Arlington, WA] One of OutBack Power's primary goals for its soon-to-be-released Radian Series GS8048 inverter/charger is to take some of the complexity out of battery-based system design and installation to increase the technology's modularity—and popularity—in the grid-tie market. The 8 kW Radian inverter/charger is a ground-up redesign that addresses three drawbacks of the company's current OutBack FX and GTFX lines: It is designed for both grid-interactive and stand-alone applications; it has a split-phase 120/240 Vac output; and it provides dual ac inputs. The GS8048 employs a vented cooling design, has a 48 Vdc nominal input voltage and 30 W idle consumption, and has surge specifications of 16.97 kVA (100 milliseconds), 12 kVA (5 seconds) and 9 kVA (30 minutes). The Radian inverter/charger features a simplified parallel design that is compatible with systems from 8 to 80 kW. General availability for the Radian GS8048 is targeted for late summer 2011.

OutBack Power / 360.435.6030 / outbackpower.com

Suntech Launches 290 W SuperPoly Module

[San Francisco] Suntech Power, the number-one manufacturer of c-Si modules worldwide, has released a new 290 W STP290-24/Vd module in the US. The 72-cell module uses 6-inch polycrystalline cells and is intended for large commercial and utility-scale projects. It has a rated efficiency of 14.9% and the following electrical characteristics: 35.6 Vmp, 8.15 Imp, 45.0 Voc and 8.42 Isc. The STP290-24/Vd module includes a 10-year material and workmanship warranty and a stepped power performance warranty of 5 years/95%, 12 years/90%, 18 years/85% and 25 years/80%.

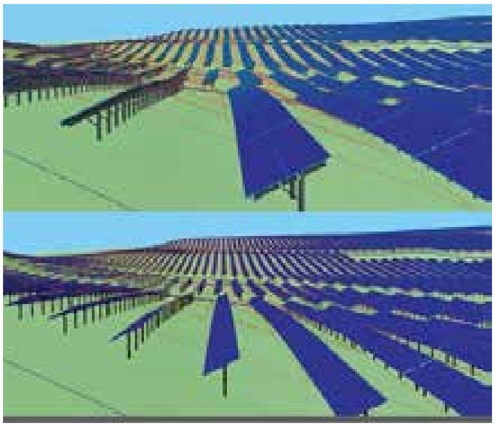
Suntech / 866.966.6555 / suntech-power.com

Solectria Expands String Combiner Line

[Lawrence, MA] Solectria recently introduced three new combiner modules with dc disconnect options. The disconnect feature is available in an eight-circuit combiner rated for 120 A maximum, housed in a NEMA 4X fiberglass enclosure; a 16-circuit combiner rated for 180 A maximum, also housed in a NEMA 4X fiberglass enclosure; and a 24-circuit combiner rated for 180 A maximum in a NEMA 4 polyester powder–coated steel enclosure. The CSA-listed load-break–rated switch is tested to UL 508 and is compliant with UL 1741 and the 2011 *National Electrical Code.*

Solectria Renewables / 978.683.9700 / solren.com

Schletter Lands Helios 3D North American Distribution



[Tucson, AZ] Schletter has teamed up with STOHER+SAUER, a German CAD application shop, to distribute Helios 3D, a software package for planning and developing large commercial and utility-scale roof- and ground-mounted PV systems. STOHER+SAUER's Helios 3D is a two-part system that includes server-based database management and an AutoCAD-based drafting interface. The database is designed to manage information such as racks, modules, array support posts, bills of materials and post location coordinates. A shared SGL server installation allows multiple users to access and update database information. Integrated design tools facilitate tasks such as rack placement; shadow object placement and calculation; row numbering; terrain analysis; and specifications for row distance, access roads and equipment staging areas. Helios 3D is used in conjunction with AutoCAD Civil 3D 2011 or 2012. Schletter recommends that users have a basic understanding of AutoCAD Civil 3D fundamentals before using Helios 3D. Schletter offers Helios 3D training and a variety of pricing and licensing options.

Schletter / 520.289.8700 / schletter.us

Trina Announces Availability of Trinamount

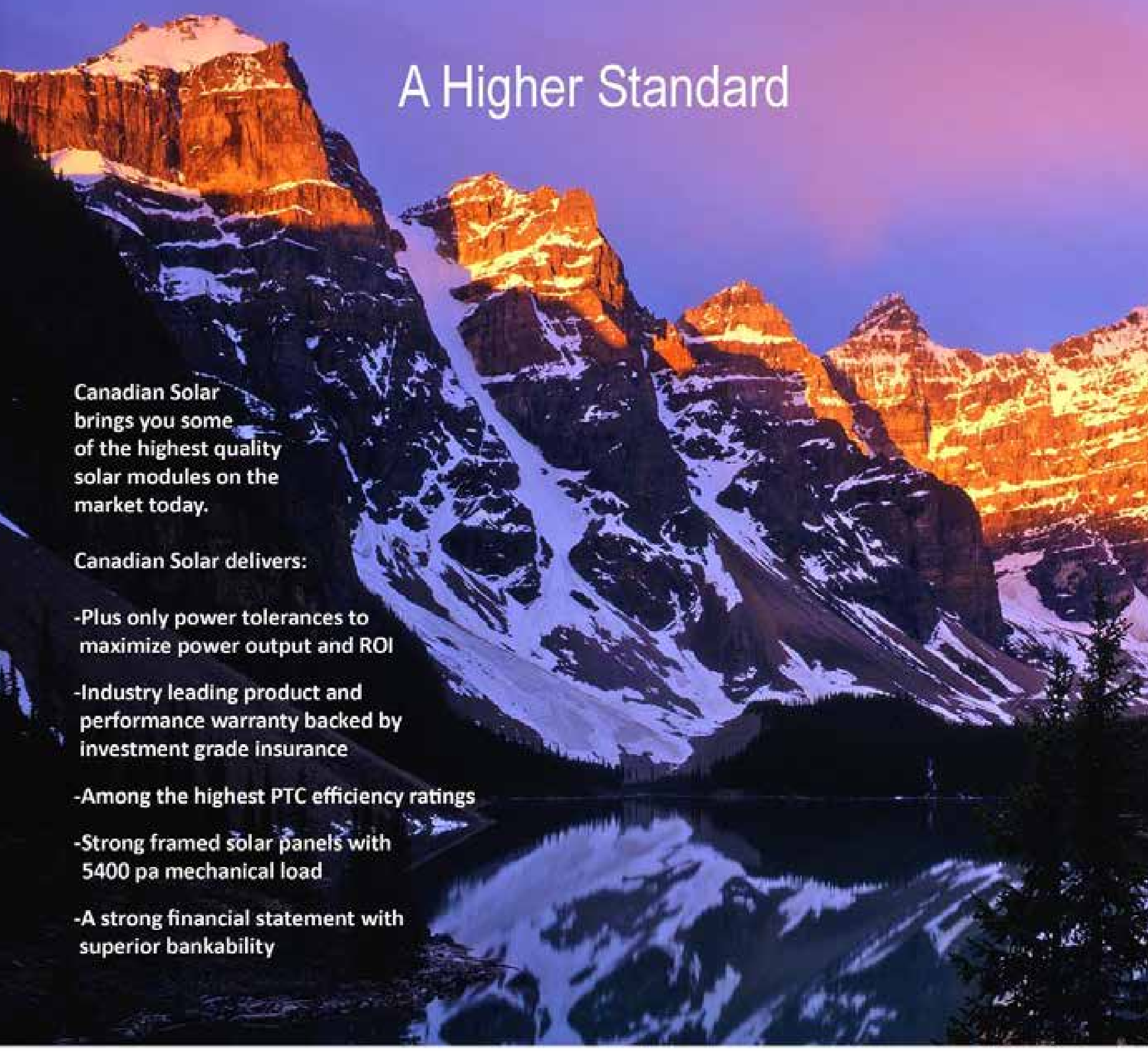
[San Jose, CA] Trina Solar is one of the latest module manufacturers to develop a fully integrated module/racking solution in partnership with Zep Solar. Trinamount utilizes a grooved frame extrusion on its TSM-PC/PA05 modules that is compatible with Zep's interlocking and auto-grounding mounting system. Three versions of the Trinamount are ready to ship to integrators working in the US and Canada: Trinamount I for tile roofs, Trinamount II for pitched roofs and Trinamount III, a ballasted system for low-slope roofs.

Trina Solar / 800.696.7114 / trinasolar.com

Metal Plus Offers Standing-Seam Roof Brackets

[Winsted, CT] For installers working with standing-seam metal roofing, installation platform brackets from Metal Plus can speed roof-mounted array installation and increase jobsite safety. The bracket line includes three models. The Ultimate Bracket is designed to support 2-by-8 and 2-by-10-inch wooden planks. Big Boy Brackets are designed for common 2-by-12-inch aluminum scaffolding planks. A third bracket type, the Roofer's Helper, is adjustable for various standing-seam widths and can be used to stage modules or support ladders laid along the roof plane. All models are adjustable for roof slopes from 3/12 to 24/12 and are compatible with 1- to 2-inch snap-lock or mechanical standing-seam roofing. Individual brackets start at $879, and package pricing for a mix of brackets starts at $6,292.

Metal Plus / 860.485.5834 / metalplusllc.com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Per on Crystalline

Compiled by David Brearley and Joe Schwartz

Topher Donahue

spectives

Silicon PV

Remember when crystalline silicon (c-Si) PV modules were selling for around $4 per watt, and it was difficult to find a manufacturer or distributor that could consistently guarantee product delivery against your purchase orders? That was not so long ago—just 4 or 5 years. It was easy to imagine under those circumstances that c-Si PV's dominant market position was vulnerable and that thin-film PV technologies were poised to make significant inroads.

To a certain extent this did come to pass. The approximate market share for thin-film PV increased from 10% in 2007 to 14% in 2008 to 17% in 2009. That same year, a thin-film PV module manufacturer, First Solar, led the PV industry in annual production capacity for the first time, outproducing traditional c-Si market leaders like Suntech Power and Sharp.

Then came a remarkable reversal of fortunes. In an article published on May 9, 2011, Shyam Mehta of Greentech Media reported: "2010 marked the first time since 2005 that thin-film market share declined (from 17% in 2009 to 13% in 2010)." Over the last 18 months, buoyed by a rapid expansion of c-Si PV manufacturing capacity in China and Taiwan and stable polysilicon prices, c-Si PV has reclaimed some of its market share losses.

As evidence of the recent increase in the number of c-Si PV module manufacturers, 53 manufacturers are included in *SolarPro* magazine's "2011 c-Si PV Module Specifications." This represents an almost 50% increase in the number of manufacturers that qualified for inclusion in our 2010 c-Si PV specifications table. As in previous years, we filtered the data to include only listed and CEC-eligible products. Even after the products from these manufacturers were filtered further to include only modules rated at 175 W or larger, the total number of c-Si PV modules available to North American system designers, integrators and installers today exceeds 800, more than twice as many products than were available just 1 year ago.

Not only are more c-Si PV products available than before, but it is also a buyer's market. Softening demand in

2011 c-Si PV Module Specifications

For 2011, we assembled our most comprehensive module specifications dataset to date. The removable Desktop Reference Guide included in this article contains manufacturer-vetted data for 486 modules from 53 manufacturers. All of the modules represented were reported to be available to integrators working in the North American PV market. Modules with an STC rating of 175 W or higher that were compliant with California Energy Commission (CEC) SB1 Guidelines as of July 1, 2011, are included. Due to the wide variance in the number of models produced by various manufacturers, some module lines are not presented in their entirety in the printed version of this guide. Modules from each manufacturer are sorted by STC rating in descending order. An expanded version of the dataset is available to *SolarPro* readers in Excel format at solarprofessional.com/pvguide. The online version of the table contains specifications for the full dataset of 835 modules.

traditionally strong European FIT markets has led to a global oversupply of PV modules, marked by falling prices. While GTM Research reports that prices for Tier 1 Chinese c-Si PV modules averaged around $2.20 per watt in 2009 and $1.75 per watt in 2010 (see Resources), the talk at Intersolar North America in July 2011 was of prices in the $1.30 to $1.40 per watt range, depending on the size of the order. Opinions differ on the likelihood of price stabilization in the near future, as it is unclear if demand in Germany is picking up in the second half of 2011.

Bargain pricing for c-Si PV is both good and bad news. It is good news for potential customers who are looking for the best deal possible. It is good news for the industry in general, in the sense that we can point to declining module prices as proof that progress is being made toward grid parity. It is bad news, however, for module manufacturers. Because market prices are falling faster than manufacturers can drive costs out of their products, their profit margins are being squeezed. If this trend continues unabated, it may prove challenging for the industry in general. Companies may fail, leaving behind unsupported products and customers.

This article gathers perspectives from multiple industry stakeholders on the past, present and future of c-Si PV. We interviewed professional engineers, industry consultants and representatives from both emerging and established c-Si PV module manufacturers. The first perspective presented is that of Bill Brooks, principal engineer at Brooks Engineering, a 24-year veteran in the solar industry.

Brooks shares some of his lessons learned about module selection in a personal history. However unprecedented this moment in time in the PV industry may seem, his account illustrates that the fundamental module selection process remains unchanged from when he purchased modules for his home PV system 13 years ago. Looking back, he concludes that while some of his decisions have stood the test of time admirably, others were clearly mistakes.

Lessons Learned from Personal Purchasing History

By Bill Brooks, principal engineer, Brooks Engineering

Perhaps the best way to illustrate where PV technology is heading and how c-Si fits into that future is to outline some of my experiences in the solar industry. In particular, I want to share some important lessons that my personal module purchasing history taught me. While my perspective is by no means comprehensive, I do have 24 years of direct experience with c-Si PV, a technology with a track record that spans nearly 60 years.

In 1988, I caught a vision of what PV technology could mean to the future of electricity production. As a result, I wanted to learn everything possible about photovoltaic technologies. When I began my quest to figure out where I fit into this fledgling industry—as a graduate student at North Carolina State University and a founding staff member at the North Carolina Solar Center—I did not have a direct frame of reference and was eager to learn from others.

I recall listening to numerous experts (and a few "experts") who assured me that the future of PV was in thin-film technology. The prognosticators of the day claimed that within 5 years—meaning by the early 1990s—thin films would dominate PV module production, and the relatively boring and much too expensive c-Si technology would be relegated to niche markets where high efficiency was much more important than cost.

Five years passed. Crystalline silicon remained the dominant PV technology. Undeterred, some of the same "experts," plus several new ones, claimed that within 5 years, thin films would dominate the market and c-Si would be history. By now I realized that this had a familiar ring to it. It was "déjà vu all over again."

Turn the clock ahead another 5 years to early 1998. Crystalline silicon was still king. Few of the original thin-film proselytizers remained. By this time, many in their ranks had been swept up in the growing dot-com excitement. While a few holdouts still made the 5-year claim, a growing body of historical evidence tempered their rhetoric.

This same year, taking a leap of faith, I decided to move my family to California where I could support the brand-new California solar rebate program by offering training services. I also wanted to participate in the program. What better way to establish credibility, I reasoned, than to build my own PV system and gain firsthand experience with the process?

When buying the first PV system for my home in 1998, I was faced with the same decision that every informed buyer faces, namely: "What will provide the best value for my money?"

TECHNOLOGY SELECTION

While there were fewer photovoltaic technology choices back then—and far fewer manufacturers—the decision process was nonetheless similar to what it is today. The options available to me were modules built using thin-film PV technologies or modules manufactured using mono- or poly-crystalline silicon PV cells.

Thin films. Products using cadmium telluride were not yet commercially available. Nevertheless, this technology showed significant promise of being an excellent low-cost cell technology. Unfortunately, few successful products had been fielded, so the track record was extremely limited.

CONTINUED ON PAGE 44

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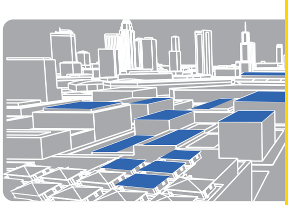

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Courtesy Solar Design Associates

Time tested Solar Design Associates designed this c-Si BIPV roof for the Carlisle House in 1979. Located in Carlisle, MA, this was the first residence fully powered by a utility-interactive PV system.

While amorphous silicon had a much longer track record in the field, reviews were mixed. Module efficiency was low and nearly always overstated by the manufacturers. Temperature sensitivity was low, but so was light sensitivity—a severe setback for a product that generates power from light. Manufacturing complexities had caused numerous plants to go bust.

At the time, copper indium diselenide and copper indium gallium diselenide had shown significant improvements in efficiency, and a major manufacturer was beginning to put them into limited production. However, manufacturing difficulties challenged the technology.

Crystalline silicon. As much as I love to try out new technologies for fun, when it came time to write the big check, my money went to c-Si PV. After reviewing the evidence, I was convinced that the durability and track record of c-Si were unsurpassed.

Scientists at Bell Laboratories discovered the photovoltaic effect in silicon in the early 1950s. By 1954, they had fielded "The Bell Solar Battery," which is described in a *Time* magazine article from May 3, 1954: "The silicon in the battery is first grown in pure crystals, cut into strips, and then impregnated to a depth of only one ten-thousandth of an inch with minor impurities. The top surface is treated with boron, whose atom has one less electron in its outer shell than silicon has; the bottom layer is treated with arsenic, whose atom has one more electron in its outer shell than silicon has."

Sound familiar? This 6% efficient "solar battery" is the first crystalline silicon PV module. While the conversion efficiency of c-Si PV cells has improved incrementally ever since, the most significant improvements came in the first 2 years at Bell Labs. Is that boring or brilliant? Or both?

In 1998, some research modules from the 1950s were still producing power nearly half a century later, and terrestrial c-Si PV modules had been deployed in the field for approximately 30 years. Whatever the technology lacked in imagination, it made up for in reliability and predictability. Today, we have a popular term for this: *bankability.*

In this case, I was the bank. Like any other conscientious consumer, I conducted a financial analysis of competing PV technologies. At that time, cost decreases for c-Si PV were slow and steady, yet the cost differential between c-Si and thin films was marginal at best. Research in the mid-1990s showed that module efficiency was important to total system cost. Efficiency differences between thin films and c-Si suggested that thin-film products had to cost about $0.65 per watt less than c-Si just to break even, due to the additional mounting and wiring costs associated with using lower-efficiency modules.

Back in 1998, I chose c-Si PV because of its proven track record and because I felt it offered a better long-term value proposition. Where is the majority of money going today, some 13 years later? Surprisingly enough, it still goes to c-Si PV.

MANUFACTURER SELECTION

If we were to roll credits now as I rode off into the sunset, you might think me a hero for making the right decision. Unfortunately, my happily-ever-after was short lived. My choice was flawed. I was seduced by low cost, as many people are today.

At that time, several of my closest friends and colleagues in the PV industry worked for a small but dynamic company called AstroPower. The company not only had solid technology but also a competitive business plan. As proof of its engineering strengths, AstroPower won nearly 90 federal grants over a 9-year period. The company was able to offer low-cost c-Si PV modules, while maintaining higher profit margins than other manufacturers, by using reject wafers from the semiconductor industry. Its success was assured.

After finding a great deal on its modules, I bought an AstroPower PV array for my home. I received both federal and state incentives. The decision seemed brilliant. My confidence in the company was so complete that I even invested some of my retirement fund in AstroPower. It seemed like a sure bet.

So where is AstroPower now? Dead and gone. AstroPower declared bankruptcy on February 1, 2004. While GE Energy purchased most of AstroPower's business assets in March 2004, it did not assume responsibility for AstroPower's warranty obligations. This means I have no direct product warranty on my PV array.

The good news is that my conservative choice of technology has saved me from total disaster (so far). Even though my warranty may be gone, the AstroPower product still works fairly well. You need a warranty only when there is a failure—unless you are a financier and need to account for the warranty on your balance sheet for financial purposes.

PRODUCT WARRANTY

Every large, established manufacturer of PV modules has had production problems. No matter the company or technology, there will be warranty CONTINUED ON PAGE 46


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issues—and even recalls—regardless of how careful the buyer is in choosing the product. The key question is what happens *when* there is a multimegawatt flaw in production? Is the owner at risk? Or will the owner receive sufficient support from the manufacturer?

At present, there are two ways to mitigate risk through product warranties. The first is the traditional method of buying products from large, established manufacturers. These are companies that back their product regardless of the magnitude of the problem. Companies with a reputation to protect normally go well beyond the minimum product standards for quality and testing, in order to eliminate potential problems before they happen. In the event that production problems do occur, they proactively minimize financial exposure.

The second vehicle for mitigating risk through product warranties is to purchase a product bond, which is essentially a third-party warranty from an established financial institution. This is essentially an insurance policy that covers the product should the manufacturer default on its warranty obligations. While this may not be as attractive as being able to rely on the manufacturer directly, it is the only way to proceed with the purchase of PV modules from a company that has little financial muscle and no track record. Almost 80% of PV companies today fall into this category.


Shawn Schreiner

Blake Gleason, Sun Light & Power: “When selecting a module manufacturer, we have to be convinced that the company will be around in the long term to support the warranty we are paying for. Price, terms and availability are critical as well. Within a given manufacturer’s product offering, we select a model based on form factor, stringing and occasionally aesthetics.”

Recommended PV Module Selection Criteria

Bill Brooks includes the following list of module selection criteria in his training classes for PV system designers, integrators and installers. The criteria are listed in descending order of importance:

1. **Track record.** What is the field experience with the PV cell technology?
2. **Qualification testing.** Is the product tested to the applicable IEC standard (IEC 61215 for c-Si, IEC 61416 for thin film)?
3. **Company experience.** What is the size of the company, and how long has it been in existence?
4. **Product warranty.** This is directly related to size and stability of the manufacturer.
5. **Electrical characteristics.** Are the voltage and power characteristics a good match with the inverter you want to use?
6. **Performance.** Are you getting the power you are paying for? This is currently very difficult to determine.
7. **Ease of installation.** Consider module size and weight, the number of electrical connections required per kilowatt, mounting options, bonding requirements and so on.
8. **Price.**

IN SUMMARY

While thin film is without a doubt *in* the future of PV, it is not *the* future of PV. Do not let the self-proclaimed experts with their 5-year plans convince you otherwise. Crystalline silicon has so much investment at this stage that it will remain in the future of the PV industry for decades, if not for the next century.

Silicon-based PV will continue to improve in cost and efficiency. The worldwide investment in solar-grade silicon processing plants, cell manufacturing and module assembly suggest that there is no end in sight for production increases. Since c-Si is inherently more labor intensive to build than other PV technologies, it seems likely that low-cost labor markets will dominate production.

Be wary of making purchasing decisions strictly on the basis of the lowest up-front cost per watt. The quality of the product warranty is critical to the life-cycle cost of a PV system. As with any product warranty, the fine print matters—and the company printing the fine print matters even more.

In the classes that I teach to PV system engineers, designers, integrators and CONTINUED ON PAGE 48


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installers, I include a slide that lists recommended PV module selection criteria in order of importance. This list summarizes what I have learned from my personal history in the PV industry. Price is at the very bottom of that list.

CONTACT

Bill Brooks / Brooks Engineering / Vacaville, CA / brooksolar.com

Perspectives on Supply Constraints

Implicit in Brooks's narrative is the notion that there is much to learn from history. Since the polysilicon supply shortage was one of the defining moments in the recent history of c-Si PV, we sought perspectives on how this came to pass and the potential for future raw material supply shortages.

Specifically, we wanted to know if the polysilicon shortage was a thing of the past. Also, as polysilicon becomes a proportionally smaller part of total module costs, to what extent do other major materials—such as silver, aluminum or glass—have the potential to bottleneck the supply chain or limit efforts to continually drive down module costs?

Bill Brooks, Brooks Engineering

"Shortages and surpluses are a natural part of a fast-growing industry that requires huge investments for manufacturing capacity increases. It takes so much capital to build silicon processing plants that a long-term robust market is the only way to draw that level of investment. While the growth rate of the PV industry over the past two decades is among the highest of any industry in recorded history, much of the existing market is still predicated on large government incentive programs that are notoriously unreliable.

"The shortage of 2008 was one of about three major shortages that occurred in the past two decades. Every time a new program provides too much incentive, whether it is in Japan, Germany, California, New Jersey, Spain or Italy (where it is happening right now), demand outstrips supply and prices rise. Once the mistake is discovered, the incentive program is shut down, demand plummets, supply is overstocked and module prices crash. It is Economics 101."

Mukesh Shah, product management director, SCHOTT Solar

"Polysilicon availability and pricing has improved substantially, and we do not anticipate any shortages in the foreseeable future. Silver pastes are a significant cost driver for cells, and with rising silver prices, the cost of pastes have gone up. Viable alternatives—copper electroplating, silver-coated copper and so on—are needed to significantly reduce the cost of silver pastes."

Thomas Young, director of investor relations, Trina Solar

"The market has witnessed a marked increase in investments for polysilicon capacity from both existing and entrant producers, along with annual growth in PV system installations. Based on successful delivery ramps and learning curves achieved over recent years, we have a high level of confidence that significant capacity additions will be realized in the second half of 2011 or the first half of 2012. So although short-term supply tightness can never be ruled out during periods of high demand growth, we believe these global suppliers can effectively meet our sector's growth requirements going forward.

Courtesy Trina Solar

Silicon wafers Prices have stabilized as polysilicon manufacturing capacity has expanded globally, leading to improved availability for PV module manufacturing.

"Beyond polysilicon, we have also seen parallel investment in the key non-Si materials mentioned, as well as new techniques and material technologies that either improve usage rates or replace such components entirely through more economically efficient alternatives."

Brian Grenko, director of operations, Yingli Green Energy Americas

"Effective planning and management of the polysilicon supply continues to be challenging for two main reasons. First, polysilicon-manufacturing expansion is costly and often requires a long cycle time relative to the oscillation of PV module demand, which is still largely driven by incentive programs. Second, the distribution of polysilicon suppliers is bifurcated between a small cartel of established companies—the ones that historically satiated semiconductor industry demand until this was overtaken by solar demand almost 10 years ago—and an overwhelmingly large number of new players. These new suppliers saw 'green' when spot market poly pricing grew by an order of magnitude preceding the collapse of the Spanish solar market and a worldwide economic crisis in 2008. Many of these new market entrants are now painfully realizing the technical challenges of producing polysilicon at a low cost structure relative to their more established peers.

"As the cost of solar energy continues to become more competitive with traditional sources of energy, the supply-to-demand balance will stabilize. In the meantime, through our subsidiary company Fine Silicon, Yingli produces a significant amount of its own polysilicon as a hedge against potential fluctuations in spot pricing.

"As polysilicon costs stabilize and decrease, we are shifting our focus toward reducing the costs associated with a variety of other materials. The recent surge in the price of silver has forced us to consider alternative conductive materials for metallization. Aluminum costs are also volatile.

"Counterintuitively, one way that Yingli has reduced the cost of solar is by *increasing* the amount of aluminum in our frame. The new UL-certified YGE-Z Series PV module, now available in the US, consists of a 46 mm frame featuring the Zep Groove, which eliminates the need for most support racking and hardware on residential roofs."

Courtesy SolarBridge Technologies

Module-integrated Unlike some other module-level power electronics providers, SolarBridge plans to bring its microinverter to market with a 25-year warranty through direct partnerships with module manufacturers.

Perspectives on Product Innovation

While c-Si PV is elegant in its simplicity, innovative products are an essential part of an industrywide effort to drive BOS costs down. However, there are many potentially revolutionary solutions vying for market acceptance, including integrated module-level power electronics, integrated grounding solutions and rail-less mounting systems. To gauge the market traction for each of these innovations, we polled system integrators and c-Si PV module manufacturers. What are they deploying or developing? What are they most excited about?

MODULE-LEVEL POWER ELECTRONICS

The tenor of these responses suggests that stakeholders are generally still adopting a wait-and-see approach.

Bradley Hibberd, director of technology, Borrego Solar Systems

"We are not currently using any module-level power electronics. We have considered this but are waiting for the technology to mature. This will likely be when the module vendors we have relationships with integrate module-level power electronics into their modules.

"Module-level power electronics will need to demonstrate performance advantages. I believe that over time they will do so—probably in commercial installations as well as the more apparent advantages in a typical residential installation."

Blake Gleason, director of engineering, Sun Light & Power

"Integrated module-level power electronics can lower BOS costs by a couple of cents, but only if the integrated electronics last more than 25 years. As soon as a module needs to be replaced because the integrated electronics have failed, all potential benefits are lost.

"We are primarily using dc-to-dc devices because we have seen too many failures with module-level inverters. Using module-level power electronics, we have seen a small increase in the detection of module performance problems, such as bad diodes. However, we have seen a large increase in performance problems with module-level electronic devices. These devices must last as long as the modules, and the industry does not seem to be there yet."

Mukesh Shah, SCHOTT Solar

"We believe that integration of BOS components and improving the efficiency of installation are key to driving down overall system cost. We are evaluating integration of power optimizer and microinverter electronics in the junction box, as well as integrating racking with the module frame. We are working with various partners to evaluate options and bring cost-effective solutions to market. We are encouraged to see that some module-level power

Topher Donahue

Lumos LSX module system The LSX200 Series integrated module and racking system from Lumos features frameless modules—eliminating module-frame–bonding requirements—and a mounting rail profile with an integrated wire way.

electronics manufacturers are starting to offer 25-year warranties to match our panel warranties."

Thomas Young, Trina Solar

"Module-level power electronics are relatively new to the PV market. At this point, we have seen significant deployments only at the residential and small commercial scale, which is an inherently small part of the overall picture."

Brian Grenko, Yingli Green Energy Americas

"We are continuing to evaluate the integration of distributed electronics technologies into our PV modules and have opened up a research and development lab in the San Francisco Bay Area to facilitate our product development efforts."

INTEGRAL EQUIPMENT BONDING

The suitability of using structural aluminum and steel mounting systems for bonding purposes has long been debated. The ability to do so greatly reduces time and material costs, but the industry has lacked guidelines about what bonding methods and hardware are appropriate with different module and mounting products.

With the introduction of UL 2703, a test standard is now in place for precisely this purpose. In order to list to UL 2703, modules need to be evaluated with specific mounting products. The market traction for products like the WEEB (washer, electrical equipment bond) from Wiley Electronics, suggests that system integrators and installers are ready to put this standard to the test. But will module companies jump through the additional hoops?

Bradley Hibberd, Borrego Solar Systems

"Grounding is a significant contributor to total installed cost. It is well understood that both material and labor costs increase if it is done properly."

Blake Gleason, Sun Light & Power

"Module frame electrical bonding that is integrated into the mechanical attachment of the module to the racking is a clear way to lower BOS costs. Module manufacturers and racking manufacturers both need to push to roll out integrated bonding products to meet new standards, such as UL 2703."

Alan King, general manager, US operations, Canadian Solar

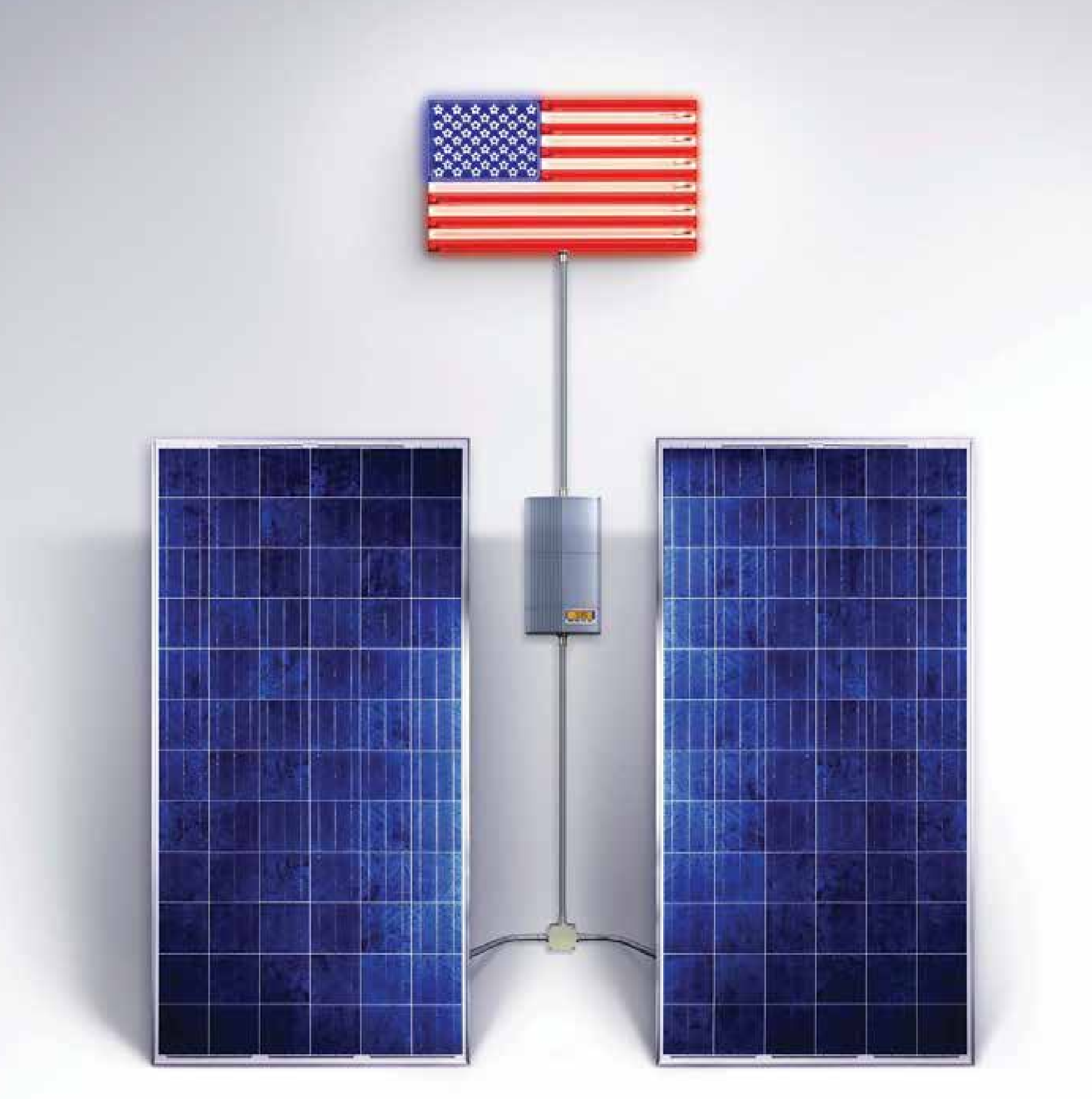
"UL 2703 is new but not too much different from UL 1703, with the additional grounding test instruction. Our approved grounding method has passed UL 1703 with the additional grounding test. There is no plan to list any products to this new standard at the moment."

Thomas Young, Trina Solar

"UL 2703 is a wonderful step in the right direction. Many module manufacturers, Trina Solar included, would like to offer installers the flexibility to choose their preferred grounding mechanism. However, the downside with WEEBs was that they were never recognized by UL, due to the inherent rigidity of the standard. The hope is that this situation can be resolved with UL 2703 by allowing alternate grounding systems, like WEEBs, to be included in the manufacturer's installation manual as a recognized means of grounding."

Brian Grenko, Yingli Green Energy Americas

"We are excited about the UL 2703 standard, because it enables racking suppliers to more easily partner with PV module manufacturers to develop equipment-grounding schemes that eliminate the need for copper-wire runs within the PV module array. Yingli Solar PV modules have been certified for use with mounting solutions CONTINUED ON PAGE 52



Courtesy Zep Solar

Yingli Solar Z-Series Yingli's Zep Compatible module frame eliminates the need for mounting rails, dramatically reduces grounding hardware requirements—Zep components are listed to UL 2703—and is optimized for use with Zep Compatible microinverters from Enphase.

offered by several racking companies, including PanelClaw, Schletter and Zep Solar. We actively seek to partner with BOS companies to reduce system costs."

RAIL-LESS MOUNTING SYSTEMS

Canadian Solar was the first PV module manufacturer to offer c-Si PV product lines with the Zep Groove incorporated into the module frame. In addition to its original flush-mount solution for residential composition shingle roofs, Zep has extended its product offerings to tile and low-slope commercial roofs, and it has a large ground-mount solution in development. As of August 2011, several other module manufacturers—including CentroSolar, ET Solar, Trina and Yingli—offer c-Si PV products suitable for rail-less mounting.

Bradley Hibberd, Borrego Solar Systems

"I believe that there is room for removing material from the combined module frame/racking system to reduce cost. In addition to rail-less mounting systems, material could also be removed from the module frame and racking systems designed for frameless modules, as some modules, mostly non-c-Si, are already."

Thomas Young, Trina Solar

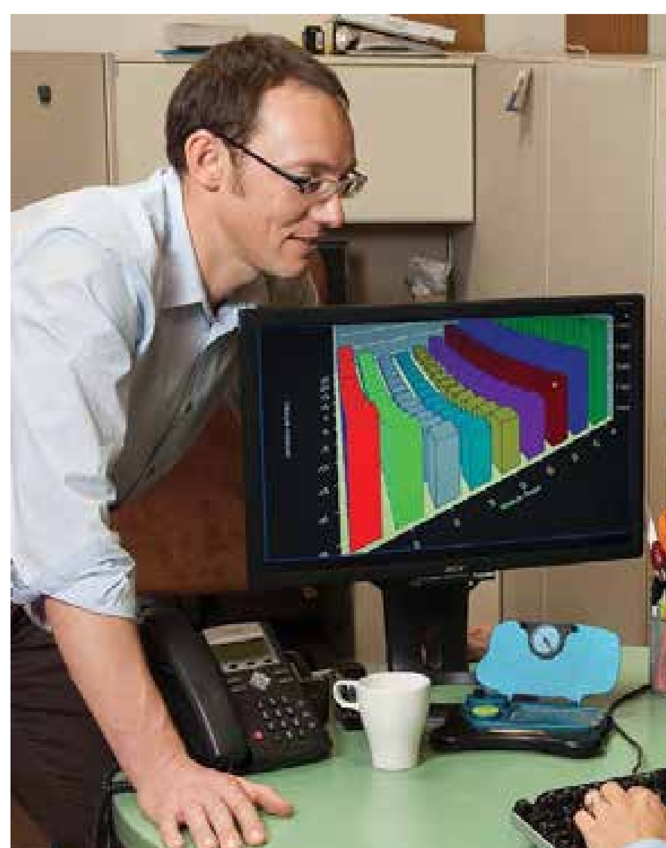
"As module prices drop from a 60% or larger portion of the overall system cost down to around 40% of the overall system cost, more attention is being paid to the BOS components. As such, Trina Solar has created a new 'Solutions Line' of product offerings.

"Trinamount, the current flagship of this new platform, enables rapid deployment of a roof-mounted PV system. It eliminates the need for rail, reduces hardware and can speed the installation process by as much as 4.5 times. Integral to its design is an additional auto-grounding feature that ensures a high-quality electrical bond by simply mounting the system. The beauty of the rail-free design is that it reduces costs by eliminating the need to ship large pieces of aluminum around the country and vastly reduces the number and size of components stocked in a warehouse."

Brian Grenko, Yingli Green Energy Americas

"The frame and electrical leads are the touch points of the PV module for installers and are a natural place for PV module manufacturers to start when considering how to reduce system costs. Ultimately, the CONTINUED ON PAGE 54

Bradley Hibberd, Borrego Solar "The key module selection criteria for Borrego Solar are those that contribute to a reliable and high-performing asset over the lifetime of the system along with pricing that allows us to win projects in the first instance. The most important criteria are pricing, product reliability, performance and the viability of a company with regard to being around to support the warranty."



Fred Speiser

incorporation of BOS technologies into the module has to provide real savings for the end user."

Product Reliability and Performance

In last year's c-Si PV article in *SolarPro* magazine (August/September, 2010), Blake Gleason lobbied for more transparent module reliability data. NREL has published a test protocol, "Terrestrial Photovoltaic Module Accelerated Test-to-Failure Protocol," by C.R. Osterwald. However, there is still no mandate, either from the market or the regulators, to test to this protocol.

Relative performance projections are another gray area for project developers and integrators. In markets with feed-in tariffs or performance-based incentives, specific yield (kWh/kW) is more important than nameplate rated power and module efficiency at STC. Here again, the industry lacks standards and transparency. As performance guarantee requirements become increasingly common, the absence of defined reliability and performance standards is increasingly problematic.

"One of the most important questions out there is how to determine module performance, specifically how to distinguish one from another," explains Borrego's Hibberd. "The lack of standardization here leads to a lot of variability between manufacturers. As a result, project developers and engineers do not have a level playing field for evaluation purposes. There needs to be industrywide consensus on an approach to modeling the performance of crystalline silicon so that there is more transparency to end users—both customers and investors," Hibberd concludes. "Production modeling currently seems more like an art than a science. I know many researchers are working in this area, but we need the level playing field now."

We asked module manufacturers what they are doing to address these needs. If they have published specific yield data, what was the source of this data? Is progress being made toward standardized measurement and reporting?

Don Massa, product manager, Conergy USA

"Since the introduction of its PowerPlus modules, Conergy has stressed the importance of yield as distinct from output at STC. In fact, an independent testing laboratory verified that the efficiency of Conergy's PowerPlus modules increases in the lower light (non-STC) conditions where modules spend the most time. CONTINUED ON PAGE 56

Courtesy Conergy USA

Conergy PowerPlus modules While standing on a PV array is never recommended, Conergy's PowerPlus modules feature a proprietary frame and structured glass that provide high mechanical strength and static load resistance (5,400 Pa / 113 psf).

In a large project where Conergy PowerPlus modules operate alongside and under identical conditions with three other well-known module brands, the PowerPlus modules show a 3% higher yield than the next-closest module. The performance of the PowerPlus modules was 5% better than what was predicted by well-known simulation programs, which may well point out the need for a test protocol that documents the performance of a module over a range of real-world conditions."

Mukesh Shah, SCHOTT Solar

"We monitor energy-yield data from our global test sites and customer systems, and compare modeled values (when available) with actual performance. We also participated in a recent TÜV Rheinland Energy Yield study and were very pleased to see that our modules ranked first among 13 modules that were tested from 11 manufacturers. The challenge with energy-yield data is how to compare data across multiple systems, accounting for various system design and environmental factors. An industry standard is being discussed, but it is not established yet."

Thomas Young, Trina Solar

"Specific yield is a better means of determining the overall potential of a PV system than nameplate output. The problem is that yield is always dependant on site-specific weather conditions. Therefore, benchmarking specific-yield values from power plants separated by any sizable geographic area is not a fair comparison.

"Tests like those conducted by the Desert Knowledge research center in Australia or by *Photon* magazine in Germany are the only accurate means of comparing module yields. Because the test is confined to a specific area for all the modules, weather can be taken out of the equation. However, that yield value represents only the specific location where the test was performed.

"One thing we have done at Trina to provide investors and integrators with greater confidence is to CONTINUED ON PAGE 58

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offer a product warranty that accounts for degradation on an annual basis."

Brian Grenko, Yingli Green Energy Americas

"At Yingli Solar, we often partner with EPC companies that are responsible for providing system performance guarantees. The terms and metrics used to define performance vary significantly amongst system owners.

"The challenge here is transforming production data into a performance metric without introducing significant errors, which may come from monitoring software, weather gauges, model error, data filtering and other sources. Signal-to-noise ratio is a real challenge when evaluating system performance degradation.

"Industry working groups that we participate in are just beginning to address this topic. As more multimegawatt projects are built, system owners progress further along the learning curve and performance requirements become more stringent and sophisticated.

"When measured in a controlled environment—where samples are processed uniformly under similar conditions and with one weather station—specific yield is simple to measure and an effective means of comparing different companies or technologies. Yingli Solar has participated in such studies, including a recently disclosed year-long survey conducted by TÜV Rheinland, in which we placed second out of 11 leading PV module manufacturers."

Food for Thought

The stakeholders interviewed for this article were invited to comment on additional topics that were important to them and that our interview questions failed to address.

Don Massa, Conergy USA

"An important question is how the evolution of the solar industry is affecting the design of total systems. At Conergy, we see a number of market factors impacting total system design. One of the foremost factors is the cost of modules. As module prices decrease, we will see more efforts to lower the relative costs of mounting systems, BOS and especially labor.

"Another factor that is increasing in importance as the industry matures is the influence of other participants, such as insurers, financers and regulators, who are evaluating the safety and system life in addition to yield. This means that the industry has to focus on increasing the lifetime yield of systems through a variety of different means. For instance, Conergy offers to the European market an integrated, optimized system in which the parts are synchronized for greater efficiency."

Mukesh Shah, SCHOTT Solar

"There is a lot of focus on low initial cost, but not enough focus on long-term value. PV systems are assets that generate electricity for more than 25 years, and customers should be better informed about the long-term value of their asset. PV modules that provide positive sorting, narrow output tolerance, better CEC rating, better power warranty and higher energy yield clearly provide a better return on investment for the system owner. It is important for installers to let their customers know that they will end up with more money in their pocket over the course of 25 years if they choose a higher-quality module."

Brian Grenko, Yingli Green Energy Americas

"While some may say it stifles innovation, component standardization has been shown to effectively serve as a vehicle for cost reduction. Standardized frame dimensions allow racking suppliers to design fewer clamps and less supporting hardware. Standardizing electrical connectors presents an opportunity for the industry to develop a safe, reliable and uniform platform for installers. This standardization alleviates their headaches with respect to procurement lead times, requiring multiple sets of specialized tools and unclear guidance on compatibility, among a host of other issues. Surprisingly—or not, depending on whom you talk to—connector suppliers remain unenthusiastic about the prospect of tackling this challenge. Meanwhile, PV module and distributed electronics manufacturers have to navigate the growing field of components available for use in their products."

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SCHOTT Solar / 888.457.6527 / us.schott.com
Trina Solar / 800.696.7114 / trinasolar.com
Yingli Solar / 888.686.8820 / yinglisolar.com

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Part One

Commercial PV System Data Monitoring

By Kyra Moore and Rebekah Hren

Project owners, developers, contractors and financers all have a significant monetary stake in PV system performance. Without accurate and reliable data monitoring, evaluating and maintaining optimal system performance is just a guessing game.

Courtesy SMA

For years, PV system data monitoring was mainly an afterthought, used primarily as an educational tool or for publicity value. However, data monitoring is now required for utility-scale PV systems, where it is used to track performance and comply with regulatory reporting requirements, and increasingly used in commercial applications. Despite happening in fits and starts, the research and development of commercial PV monitoring systems is resulting in more creative and ingenious solutions that streamline system integration and installation. At the same time, the variety of solutions and providers is increasing.

These coincident trends offer an opportunity and a challenge. PV system integrators and installers are used to developing and implementing code-compliant electrical and mechanical designs. However, mastering the myriad variables that an IT component adds—with its new terminology, hardware, architectures and configurations—can prove challenging. In addition, while the cost for specific PV monitoring services is declining, the total price to monitor large PV systems may actually be increasing as more functionality is expected from data monitoring systems as a whole.

Working in PV project development and construction, we have seen firsthand the difficulties developers and integrators encounter when data monitoring systems are not specified until near project completion. To control the associated component and installation costs and optimize system reliability, data monitoring must be given a seat at the design table.

In this two-part article, we describe the value proposition of monitoring commercial PV systems. In Part One, we consider data monitoring options, components and selection criteria, as well as the pros and cons of various levels of monitoring granularity. We explain how monitoring networks transfer information from one place to another. In Part Two, we will examine site-specific considerations, potential design and hardware responses, and provide a cost analysis case study. Throughout, we reference best practices and common mistakes.

Value Proposition

Because monitoring systems provide a remote visual representation of PV system performance, they are valuable tools for system owners, investors, installers and operators. One way to ensure that PV systems are operating optimally is to physically go on-site to take instantaneous irradiance, cell temperature and inverter output power measurements. You can then calculate whether the actual system output power acceptably approximates the expected output power. (See "PV System Commissioning," October/November, 2009, *SolarPro* magazine.) Alternatively, you can specify a monitoring system to continuously provide the desired level of performance assurance.

Over the past few years, a major shift has taken place in the way PV systems in North America are evaluated. The standard of evaluation used to be based on capacity (kW or MW), meaning either the installed dc nameplate-rated power (kW_{STC}) or the capacity at PVUSA test conditions (kW_{PTC}). Now the emphasis has moved to ac energy production (kWh or MWh) or specific yield (kWh/kW or MWh/MW). According to Bill Reaugh, VP of project development at Draker Laboratories, a data monitoring hardware and services provider, "The PV industry in the US and Canada has moved from simply trying to install the most capacity possible to trying to get the best energy harvest, because we are catching up to Europe both in operating practice and incentive structure."

The goal of plant production estimates is to calculate expected energy production or specific yield for a PV system as accurately as possible by modeling component performance across a range of operating and environmental conditions. However, system downtime is potentially the greatest loss factor for total system performance. Even if you have the highest efficiency modules mounted on the most sophisticated tracking system available, money is lost every minute that the sun is shining and the system is out of service or operating suboptimally, for whatever reason.

In the experience of Thomas Tansy, VP of business development at Fat Spaniel Technologies, a monitoring company recently acquired by inverter manufacturer Power-One, PV plant monitoring is a given in utility- and industrial-scale applications. "In this context, data monitoring has the potential to generate the highest return on investment and is required 100% of the time," he explains.

Data monitoring systems that are well designed, installed and maintained can ensure that a PV asset achieves the highest return on investment by minimizing operations and maintenance (O&M) costs and system downtime. Not only is the risk of underperformance or nonperformance unacceptable to owners and investors, but federal laws also define and specify data monitoring requirements for utility-scale PV systems that fall under the jurisdiction of the Federal Energy Regulatory Commission and the North American Electric Reliability Corporation.

"No traditional power plant would be built without extensive monitoring for determining that it is operating properly at all times and figuring out what is wrong when it is not," notes Chuck Wright, principal at PowerDash, a monitoring services provider. "Likewise, renewable energy will not be a serious component of the world energy supply unless monitoring is an integral component. It is just a cost of doing business properly."

Nevertheless, Power-One's Tansy observes, "At the residential scale, data monitoring is often considered optional because performance-based incentives are generally not involved." While it is certainly possible to build a business case for offering data monitoring as a standard feature on residential PV systems (see "Making the Case for Residential PV System Monitoring," August/September, 2009, *SolarPro* magazine), the industry has not yet matured to the point that this is considered part of the cost of doing business for these systems.

In practice, the status of data monitoring in commercial-scale PV systems is somewhere in the middle. Depending on

Alarm triggers Monitoring solutions with customizable alarm triggers are useful for O&M purposes. In this case, the loss of ac power has triggered a low-performance index alarm. Because Draker Laboratories' interface allows alarm preconditions to be set by the user, it is possible to reduce and eliminate false alarms.

Courtesy Draker Laboratories

the value of the energy or the details of the O&M contract, data monitoring may be considered either essential or optional.

"Monitoring systems are usually required for commercial PV plants that derive revenue from production and environmental incentives," notes Tansy. He continues: "They are likewise mandatory if maintaining consistent uptime is required or if the system owner is obligated under a production-based contract to the energy consumer. Monitoring can also be used to enable green marketing and environmental accounting."

Summarizing the added value gained from data monitoring, Blair Kendall, director of business development at Southern Energy Management, a North Carolina–based PV integrator, says: "High-quality, accurate and accessible solar PV monitoring for commercial systems serves two primary objectives. The first is to provide certainty to CFOs and investors that they are getting what they pay for. The second is to facilitate effective O&M on the system to ensure maximum system uptime and production. Both of these goals are really about mitigating investment risk that further facilitates greater investment in commercial PV systems."

Courtesy DECK Monitoring

Public display Brand-conscious businesses, educational institutions and government entities often want to make their investment in renewable energy visible. Publicly accessible dashboard options vary, both in the level of the technical details provided and the complexity of the graphic representation.

> **"Steadily declining module prices have served to increase the size of commercial PV systems. However, as financing can be difficult to obtain, the need to have an effective solar performance monitoring system to verify and sometimes guarantee system performance becomes that much more important to investors."**
>
> —Mark Lane, ArgusON

Value to owners and financial backers. According to Adrian De Luca, VP of sales and marketing at Locus Energy, a provider of software solutions to the distributed renewable energy market, the value of data monitoring for system owners and investors is twofold. "First, monitoring systems enable accurate and timely customer billing," he notes. "Second, they maximize system uptime and therefore the return on investment."

For owners and backers of commercial-scale PV systems in particular, the ability to manage a portfolio of distributed PV plants in a unified manner may be as important as the ability to track individual plant performance. Many monitoring solutions providers offer multiplant, portfolio-level management. The caveat, of course, is that data for every site must be centralized with a single vendor.

Because they can optimize system performance and return on investment, data monitoring solutions also reduce financial risk. Financing large PV systems is often contingent upon having a performance guarantee contract in place as a risk mitigation mechanism for investors. (See "PV Performance Guarantees" June/July, 2011 [Part One] and August/September, 2011 [Part Two], *SolarPro* magazine.) Data monitoring is central to every performance guarantee—it gives the guarantee its teeth and makes it enforceable.

Without accurate data monitoring, actual system performance in the field cannot reliably be compared to what was guaranteed. Therefore, performance guarantee terms need to outline minimum data monitoring requirements commensurate with the performance risk. Uncertainty in data collection may make it difficult, if not impossible, to collect damage payments.

While performance guarantees may not be in place for the majority of small- to medium-sized commercial PV systems, the basic premise holds. Effective data monitoring not only helps to identify system performance problems, but it also helps to resolve them.

"Constantly measuring power production against expected performance benchmarks allows the owner to determine if and when remedial action is necessary," explains Mark Lane, director of product management at ArgusON, a provider of site monitoring and services. "Assisting system integrators or O&M providers to resolve CONTINUED ON PAGE 64

problems and get solar power systems back online as quickly as possible is part of the value that data monitoring adds for owners and financiers," he concludes.

Public kiosks, wall-mounted displays and open-access web-based interfaces—common monitoring system features for educational institutions and brand-conscious businesses—also have value for system owners. These features add a visual or interactive component to an otherwise invisible electrical process. If a company or institution wants to showcase the fact that it has made an investment in solar for PR purposes, it can do so via a kiosk or wall-mounted display in a building lobby, online via its website, or both.

Educational displays are especially important when local or federal government entities are involved, either as customers or underwriters. "Many projects funded by the recent Federal ARRA program actually require public education displays," notes Reaugh of Draker Laboratories.

Value to installers and O&M providers. Although there are few moving parts, PV systems do require maintenance, and monitoring systems can allow integrators to efficiently allocate resources and quickly identify essential tasks.

"The role of the PV integrator no longer stops at the commissioning of the system," notes David Boynton of Southern Energy Management. "With 25-year equipment warranties, the expectation is that the system will be up and running for decades," he continues. "Performance guarantees, operations and maintenance contracts and limited installation warranties are now commonly included in a project's scope of work to ensure that the system continues to perform as expected."

While monitoring can bring some new challenges during installation, most integrators attest to the long-term benefits in terms of time and money savings for O&M services. According to J.R. Whitley, Southern Energy Management's O&M manager, "Accurate and reliable monitoring is quite possibly the most important tool in the operations and maintenance tool kit, allowing immediate notification of system issues that without monitoring would not be discovered until a scheduled maintenance trip or an angry call from a system owner."

Commercial monitoring systems are Internet-based, providing installers remote access through web portals. This enables centralized operations to manage maintenance and service activities for systems that are physically spread out. These portals can provide quick verification of system performance based on actual environmental conditions and also allow for in-depth analysis of actual system performance versus predicted performance.

Alerts signaling low system performance or equipment alarms appear on the portal to direct attention to potential issues. These alerts and alarms can also be sent directly to the service department or project manager via email, text message or both, as specified by the in-house monitoring system administrator.

The efficiency of O&M activities can also be increased with effective system monitoring. For example, the additional level of detail that inverter-direct, string-level or module-level monitoring affords can enable a system integrator or O&M provider to remotely troubleshoot the type of failure or to identify the general vicinity or even the exact location of a failed component.

"Maintenance costs are reduced if maintenance crews no longer have to spend significant time troubleshooting problems," notes Jeff Krisa, senior VP of sales and marketing at Tigo Energy, a provider of module-level hardware and software solutions for monitoring and optimizing PV plant performance. "Armed with the right information, crews can go straight to the source of the problem," he continues, "and they can bring exactly what they need to fix it."

Monitoring systems are also useful for reducing unnecessary truck rolls due to false alarms. Whitley observes: "Everyone has gotten that phone call: 'Why didn't my system produce as much energy this June as it did June of last year?' Having analytic tools at your fingertips allows you to deliver a logical explanation, backed up with tables and graphs of time-stamped data. This is preferable to the alternate response, 'I think it has been cloudier this June than it was last year,' which never leaves anyone satisfied."

In addition to the many specific uses that system integrators and O&M providers have for PV data monitoring over the service life of an operational PV system, there is a potential value to the installer at the point of sale. In his *SolarPro* article, "Making the Case for Residential PV System Monitoring," Brian Farhi, VP of business development at SolarNexus, a provider of solar business management software, observes that "[PV system monitoring] presents a great opportunity to differentiate yourself from your competitors, which can give you a competitive advantage in a tough market."

Basic Monitoring Concepts and Components

PV system designers, integrators and installers are rarely IT experts. However, it is important that they understand basic IT concepts and can identify the major components in a data monitoring system. PV system installers are often expected to install and supply power to data monitoring system components, as well as to source and install the necessary conduit, cable and connectors.

To the extent that data monitoring is part of the scope of work, it needs to be included in the plan set—and not just as a separate, vendor-supplied, single-line item. Ideally, PV system designers call out the conduits and receptacles that the data monitoring system requires within the electrical plan set for the PV system itself. After all, this is what the installers are working from.

To ensure successful execution in the field, the best practice is for PV system integrators to coordinate or partner with a monitoring system provider during the project planning stage. The concepts and components detailed in the following pages assist PV system designers with this process. Note that all communications systems should comply with Chapter 8 of the *NEC*.

Physical layer. The physical layer of a data monitoring system includes all of the hardware: sensors, meters, conduit, cable, loggers, wireless transmitters and receivers, combiner boxes, inverters and so on. The physical layer is what is generally represented on the plan sets and is CONTINUED ON PAGE 68

NETWORKING EXPLAINED

By Bill Reaugh, VP of project development, Draker Laboratories

A TCP/IP (transmission control protocol/Internet protocol) network is created in several layers, or programming abstractions: the link layer, the Internet layer, the transport layer and the application layer. However, TCP/IP is only one type of network that can be used to transfer information from one place to another. Open data protocol (ODP) is another type of network architecture; Modbus and CANbus are others.

Each network type has varying numbers of layers, but all are built up in a similar way. Each layer of abstraction allows the layers around it to function without having to know the specific programming needs of the others. Information is passed through each layer, from the source to the destination, based on the needs of the network.

Physical layer. A data monitoring system's physical layer is the network hardware. This includes the cables, jacks, connectors, computers and other physical devices that are connected together. While this is not technically a layer of programming abstraction, it is required for the other layers to exist. For example, CAT 5 cable, RJ-45 connectors and jacks and Ethernet cards are all physical components in a TCP/IP network.

Link layer. This is the basic structure used to connect one device to another. The link layer is where individual devices are addressed, generally by a media access control (MAC) address in a local area network (LAN) or wide area network (WAN). Note that MAC addresses are specific to the hardware and generally permanent. This is also the level where things like virtual private network (VPN) connections are created.

Internet layer. Message routing takes place at the Internet layer. Devices are assigned an IP (Internet protocol) address that in a manner of speaking tells physical layer devices, like routers and switches, who they are. These IP addresses act as a proxy for the MAC addresses used in the link layer.

IP addresses can be dynamic, meaning that the device or MAC address currently using an IP address may be different today than it was yesterday or even 5 minutes ago. Devices called dynamic name servers (DNS) keep track of the MAC and IP address associations as they change and also allow for domain names to be used in lieu of IP addresses. For example, you probably do not recognize IP address 74.125.224.112—but because of DNS it has a recognizable domain name: google.com.

Transport layer. The protocol used to send IP data packets is assigned at the transport layer. The most common is TCP (transmission control protocol), but UDP (user datagram protocol) is also widespread. TCP and UDP provide the structure and error checking required for a packetized data transmission system.

In a packetized system, a message is broken into small fragments. Each fragment is then sent across the network in a "best effort" system, meaning each finds its own way from source to destination. TCP and UDP rebuild the message from all of the bits, make sure they have all arrived and are in the correct order and request that missing ones be resent.

Application layer. The main user interaction with the system occurs at the application layer. HTTP (hypertext transfer protocol), FTP (file transfer protocol), SMTP (simple mail transport protocol) and many other protocols exist at this level.

HTTP, of course, is the backbone of what is commonly referred to as the *Internet.* It can be secured, encrypted or open, depending on the users' and programmers' desires. Applications at this level can be written in a variety of languages, but the most common include HTML (hypertext markup language), XML (extensible markup language) and JavaScript.


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Courtesy Draker Laboratories

Hardware components In this base station from Draker Laboratories, RS-485 lines from the inverter(s) and energy meter(s) terminate on the terminal block to the top left. The main datalogger, top center, includes a compact flash backup memory card and is backed up by the battery, which is charged by the small battery charger mounted above the battery. To the right of the battery is a din-rail mounted power supply. The white, vertical items are RS-485 to RS-232 protocol converters. A cell modem, top right, allows for remote Internet access.

the basis for connecting all of the necessary components of the monitoring system together. (The relationship between the physical layer of a data monitoring system and the programming layers is described in the sidebar on page 66.)

Bus driver. A bus driver is a method of data transmission that defines how voltages or currents on a serial communication bus should be interpreted. Examples of bus driver standards are RS-485, RS-232, and RS-422.

Protocols. A protocol is a program language that electronic devices use to transmit data to one another. One common example is the Modbus protocol, published by Modicon in 1979. Modbus is one of the most widely used protocols in the US because it is an "open" protocol. An open protocol is one that manufacturers can build their equipment to use without paying royalties or license fees to the publisher. TCP/IP (transmission control protocol/Internet protocol) and DNP3 (distributed network protocol 3.0) are also widespread. Proprietary protocols come in a variety of flavors from various equipment manufacturers.

"There are two main pieces to solar performance monitoring: accurate data collection and consistent data upload. Occasionally, a monitoring system is installed and verified to be collecting data accurately, but without confirming that data is being actively uploaded. To avoid this, make sure the monitoring system's network requirements are well understood by the site's IT manager."
—Adrian De Luca, Locus Energy

Ideally all devices in your monitoring system network use the same bus drivers and communication protocols. This is not always necessary, however: some dataloggers are capable of speaking more than one protocol and may even be able to do so simultaneously. When incompatibilities arise—generally this occurs with proprietary protocols—translation devices, or *protocol converters,* can be deployed.

"Putting in a little bit of time on the front end will save it tenfold in the field," advises Whitley of Southern Energy Management. "Monitoring systems have so many options and possible configurations, and the installation manuals often leave something to be desired," he warns. "If all the components are not sourced from one supplier, confirm that they are all using compatible protocols and have worked together on other sites. Otherwise, you run the risk of wasting time later chasing phantom alarms."

Network. A monitoring network can be connected in a variety of ways—point to point, daisy chain or peer to peer—depending on the bus driver and protocols used.

The simplest network consists of two devices connected directly to each other. The devices could be connected by a two-pair twisted cable, such as Belden 9842 cable, and use the RS-232 bus driver to transmit data via the Modbus protocol from one device to the other.

Using a similar type of cable, Belden 9841 or 3601A, it is possible to connect several devices in a daisy chain. In this case, an RS-485 bus driver can be used with the Modbus protocol to collect data from all the devices. Data is collected at a single point, usually a dedicated special-purpose datalogger.

Finally, a third arrangement is a peer-based network using TCP/IP and CAT 5 or CAT 6 cables. This system is installed much like a local area network for computers. However, each device would be an energy meter, inverter, combiner box, datalogger and so on.

Wireless devices could replace any or all of the cables in these sample networks and generally run their own bus drivers and protocols to simulate or replace those used on hardwired connections.

In conversation, *Ethernet* and *Internet* are sometimes used interchangeably, like PV panel and module, but they are not the same thing. An Ethernet network is any network built with TCP infrastructure in mind. The Internet is the collection of computers, servers and sites that we call the *web*. The ubiquitous "www" refers to an earlier nomenclature: World Wide Web.

While it is possible to create an Ethernet network that is separate from the Internet, the Internet cannot exist without Ethernet networks. An example of just such a separate network is a Modbus TCP network in a utility-scale PV plant. This network uses Ethernet devices—cables, connectors and switches—but uses Modbus at the application layer instead of HTTP or other protocols.

Communication cables. Generally speaking, communication cables use one or more twisted pairs of stranded (7x30 or 7x32) small-gauge wires, usually 18 to 24 AWG. Using twisted-pair cable minimizes radiated and conducted electromagnetic interference (EMI).

Different bus driver standards allow for longer or shorter transmission distances. RS-485, the most commonly used bus driver, is specified to transmit data for up to 4,000 feet. This distance is achieved in part by the standard itself, which uses positive and negative voltages for 1s and 0s, as well as the EMI resistance offered by the cable type. RS-232 specifies positive voltages for 1s and no voltage for 0s. A bus driver that uses RS-232 is inherently more sensitive to line noise and interference. Even with the same EMI resistance, this specification allows connection only up to 50 feet.

CAT 5, CAT 5e and CAT 6 cables—which consist of four twisted pairs of wires and terminate with RJ-45 connectors—were created to carry larger amounts of data. While additional carrying capacity is needed as networks become more complex, CAT 5 or CAT 5e cables are sufficient for the transfer rate needed for most PV monitoring applications. The bus driver behind TCP/IP-based communication provides for a transmission distance of only 300 feet between networked devices. Devices like routers, switches and hubs may be used as repeater stations to increase the distance between devices.

Like other types of electrical cable, the wires in a data monitoring system are used to carry electricity. In this case, voltage and current signals are used to communicate data within the monitoring network. Longer cable runs reduce the force or amplitude of data monitoring signals in a process similar to voltage drop in power conductors. This gradual loss of intensity is known as *attenuation.* CONTINUED ON PAGE 72

Wireless networking SMA offers Bluetooth technology in its new inverters, with optional signal repeaters, to enable wireless communication with its Sunny WebBox, reducing or perhaps eliminating the need to route cables between inverters and other equipment.


Courtesy SMA

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The reason that distance limits are defined for each bus driver has to do with the ability of devices to differentiate between 1s and 0s as the signal is dissipated across the cable. Most communication protocols have error detection routines that identify data corrupted by signal attenuation, but this only forces the master device to request the same data multiple times. In most situations, it is best to keep cable runs as short as possible and to minimize the amount of EMI-producing equipment in the vicinity.

On a final note, be aware that cable manufacturers may have multiple cables with the same basic specifications—for instance, one twisted pair, 18 AWG, shielded, with drain—that are differentiated by insulation properties like oil resistance, burial rating, UV resistance and so forth. As when choosing power conductors, make sure that you are selecting communication cables with the proper environmental resistance properties for your application. Installing indoor-rated cable in a buried conduit results in a malfunctioning monitoring system in short order.

Datalogger. A datalogger, also called a *data acquisition unit,* is an electronic digital processing device that resides in the physical layer. This device records data over time and has internal memory for data storage. Some dataloggers can also function as analog-to-digital signal converters or Internet gateways, or have other capabilities.

In a network, a "master" device initiates communication between the "slave" devices and itself. In a PV monitoring system, the master device is usually the datalogger. Slave devices, which all have unique network addresses, may include inverters, weather station equipment, energy meters of revenue grade or lower accuracy, building load or net-energy meters and so on.

Weather sensors. Weather sensors measure the environmental conditions in which the PV system is operating. Examples of weather sensors include pyranometers to measure sunlight intensity (irradiance) and sun hours (insolation); thermometers, thermistors, thermocouples or other devices to measure cell or ambient temperature; anemometers to measure wind speed and vanes to measure wind direction; barometric pressure sensors; precipitation meters to measure rainfall; and many others.

While revenue-grade plant metering is essential for billing and reporting purposes, its value is limited within the context of O&M. Plant operators need additional information in order to determine if a PV asset is performing as expected and to optimize scheduled and unscheduled maintenance activities. Weather sensors provide this additional information.

According to Blake Gleason, director of engineering at Sun Light & Power, an integrator based in Berkeley, California, "Plane-of-array irradiance and module cell temperature are all that you really need to check an array's performance ratio." A pyranometer or reference cell mounted in the same plane as the PV array typically provides irradiance data. A thermistor or thermocouple mounted on the back of one or more PV modules typically provides cell temperature data.

As characterized by Matt Taylor and David Williams in part one of their *SolarPro* article on PV performance guarantees (June/July, 2011), the *performance ratio* for an operational PV plant "separates out the uncertainty and variability of irradiance and is intended to normalize out weather factors to produce a consistent measure of system performance." It is an index of PV plant performance, usually expressed as a percentage rather than in units, that represents the ratio of actual metered PV output power as compared with the ideal irradiance- and temperature-corrected output power.

In the context of unscheduled O&M activities, the value of monitoring a PV plant's performance ratio is that this index can provide an early indication of installation or commissioning problems. Tracking this index can also be used to optimize scheduled maintenance activities, such as array cleaning. This is because the cumulative effects of dirt and dust buildup show as a steadily declining performance ratio. A stepwise or gradually progressing decline in performance ratio can indicate other issues, such as blown string or subarray combiner box fuses, stolen modules or inverter failures.

"While it might seem unnecessary," notes Southern Energy Management's Whitley, "I recommend getting a full weather station package, with sensors for ambient air temperature, wind speed and direction, global horizontal irradiance and precipitation. The worst kind of data is the data you wish you had when you need it."

> **"We have seen operators make the mistake of using a single data collector or logger for a large plant. If this device fails, then the operator is likely to lose all visibility into plant operational performance."**
>
> —Thomas Tansy, Power-One

Power-One's Tansy concurs, explaining: "Precipitation data is useful for predicting when to wash panels. Wind speed and direction are useful for discriminating the effects of ambient temperature on performance versus some other heat-induced system defect." According to Tansy, skimping on environmental monitoring is one of the most common mistakes made when data monitoring solutions are implemented: "Installers routinely omit environmental monitoring from their plant installations and then scratch their heads when system owners ask 'Why didn't my plant produce last Tuesday morning?'" he says. "The answer is often 'it was raining' or 'the ice hadn't melted from the panels' or something similar." CONTINUED ON PAGE 74

When you are designing PV systems for large acreages or sites with variable terrains, consider incorporating multiple weather stations for more specific performance ratio calculations. In many cases, projects scaled for utility-power production require multiple weather stations for this very reason. Tansy recommends that designers "segment large plants into subsegments and use a cascading design for plant data collection devices."

It is also important to follow the manufacturer's instructions when installing weather monitoring hardware. For example, the correct placement of irradiance and temperature sensors is critical.

"Many weather sensors provide output signals on the order of microvolts or millivolts," notes Draker Laboratories' Reaugh. "As a result, the sensitivity of the datalogger or analog-to-digital converter is of prime interest when reading the output of these sensors," he continues. "An analog-to-digital converter that cannot distinguish measurements smaller than 1 millivolt is useless when connected to a sensor that outputs in microvolts."

For a similar reason it is advisable to keep the cables connecting the weather sensors to the datalogger as short as possible to avoid the loss of signal strength.

Weather sensors Weather stations are essential for determining the performance ratio of an operational PV system. At a minimum, sensors are needed to measure cell temperature and plane-of-array irradiance. The latter is accomplished using a pyranometer, shown below.

Courtesy Draker Laboratories

Energy meters. In addition to solar irradiance and cell temperature, a third measurement is essential to array performance ratio calculations: delivered ac energy, which is recorded by the energy meter.

All revenue-grade energy meters conform to American National Standards Institute (ANSI) Standard C12.20 and are required to provide energy readings to within ± 0.25%. Energy meters collect data from current transducers (CTs) and may also have voltage transducers for high-voltage applications above 600 Vac. The energy meter processes the current and voltage information in a variety of ways and communicates it to the datalogger.

In its most basic form, an energy meter provides a continuous record of the kilowatt-hours that pass through the wires it is monitoring. More advanced meters can also provide additional information about the electrical system—power factor, reactive power, power quality, peak demand and so forth—based on whatever is of interest to the customer, the utility or the entity selling energy to the utility.

Most incentive programs now operating in North America require the use of revenue-grade meters to collect a record of the energy produced and a monitoring services provider to formally vet and report that data. All revenue-grade meters are calibrated against defined standards. The manufacturer or testing facility should be able to provide a calibration certificate from the National Institute of Standards and Technology (NIST), ANSI or an equivalent institution.

Some inverter manufacturers—such as Advanced Energy, Solectria Renewables and others—are now offering revenue-grade metering capabilities within their central inverters. Alternately, a revenue-grade meter can be part of the hardware package supplied by a third-party monitoring provider. Revenue-grade metering also offers the system owner and financers the ability to verify utility-provided metering and billing against a separate, independent dataset.

Note that many energy meters need an external power supply. Others draw power from the voltage connection they are reading. Consult the meter manufacturer's documentation regarding power supply requirements, terminations and fusing.

Internet gateway. All monitoring services providers use a web-based interface to display, analyze and report data collected at the project site. To get the data from the project site to the Internet cloud, a gateway of some sort is required.

Collected data can be transmitted wirelessly via a cell phone or satellite modem or via a hardwired connection, such as CAT 5, cable, DSL, T-1 or fiber optic lines. Many utility-scale sites have no access to hardwired Internet connections, so cell modem reporting is generally the only option. This requires additional upfront hardware cost for the modem, plus ongoing monthly fees for cell service. However, the simplicity of the connection provided by a cell modem often offsets the time and trouble caused by negotiating with CONTINUED ON PAGE 76

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customers and their IT teams to get the necessary permissions established and maintained over the 25-year life of the project.

The frequency of data transmission varies by manufacturer—from about once per minute to once every 15 minutes. If Internet connectivity is temporarily unavailable, some dataloggers may store data in internal memory until reconnected. Dataloggers generally need a separate power source, which might output 120, 240, 277 or 480 Vac depending on the power supply configuration. Consult CONTINUED ON PAGE 78

Courtesy DECK Monitoring

Multiple portals Different web portals may be necessary to satisfy the needs of different audiences. Public dashboards, like the top one shown above, can be used for PR purposes, such as public displays and corporate websites. Administrative portals, like the one on the bottom, provide insights into plant performance, which can be useful for O&M purposes.

your vendor's installation requirements to determine the needed power supply, terminations and fusing.

Web portal. A web portal functions as an access point for information on the Internet. While all currently available commercial and utility-scale PV data acquisition systems have some sort of web portal, their functionality and presentation format varies widely.

Multiple portal interfaces are common. For example, there may be an open-access customer portal in addition to a password-protected O&M portal. Commercial PV systems that serve educational or PR purposes may have yet another web portal.

Multiple portals are essential for utility-scale PV systems, which should have a portal for O&M that is separate from the owner portal. From the O&M portal, it is typically possible to view error alerts and manage work orders for all of the systems being monitored.

Degrees of Granularity

PV systems can be thought of as a network of subsystems, much like a river. Just as you could not determine the volume of water in a tributary feeding into the Mississippi River by measuring the total volume of water pouring into the Gulf of Mexico, you cannot determine individual PV component performance by looking at only the ac output at the end of the system.

In a PV system, power is combined at module, string, combiner box, subarray and inverter levels. It is possible to collect power data at each of these points. Higher levels of data granularity provide a more complete look at total system performance. The further a PV system is divided, the more available data there is for benchmark comparisons and troubleshooting.

Unlike a river, the electrical design for PV power systems is generally characterized by system symmetry—by the repetition of similar, if not identical, subsystems. This principal of symmetry is useful when determining the optimal degree of monitoring for a PV system.

To the extent that a PV system design is electrically symmetrical, it may be possible to reduce the amount of granularity needed to adequately monitor the system. For troubleshooting or O&M purposes, manually or automatically comparing the power output at equivalent collection points in a PV system can provide a level of functionality that is similar to installing a more complex and granular monitoring system. CONTINUED ON PAGE 80


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For example, if a PV system designer plans to use 10 source-circuit combiner boxes to aggregate power into a single central inverter, each with an identical number of string inputs, then all 10 PV output-power circuit conductors should essentially carry the same amount of power when averaged across a period of minutes. Therefore, if the output of these combiner boxes is monitored, then a combiner box with lower-than-expected power output can be spotted at a glance by comparing the power curves taken at each combiner.

Assuming a symmetrical electrical design, source-circuit combiner box-level monitoring can provide string-level insight into system performance at a fraction of the cost and complexity of string-level monitoring. While monitoring at the combiner box level would not identify exactly which source circuit is not contributing, it *can* identify that a string has failed and, in this example, target the troubleshooting activities required to fix the problem to just 10% of the array.

Similarly, string-level monitoring can be used to provide module-level insight. In fact, monitoring pairs of ungrounded current-carrying source-circuit conductors may effectively achieve this level of granularity at a relatively reduced cost. The challenge for system integrators is determining at what point additional granularity no longer justifies additional costs.

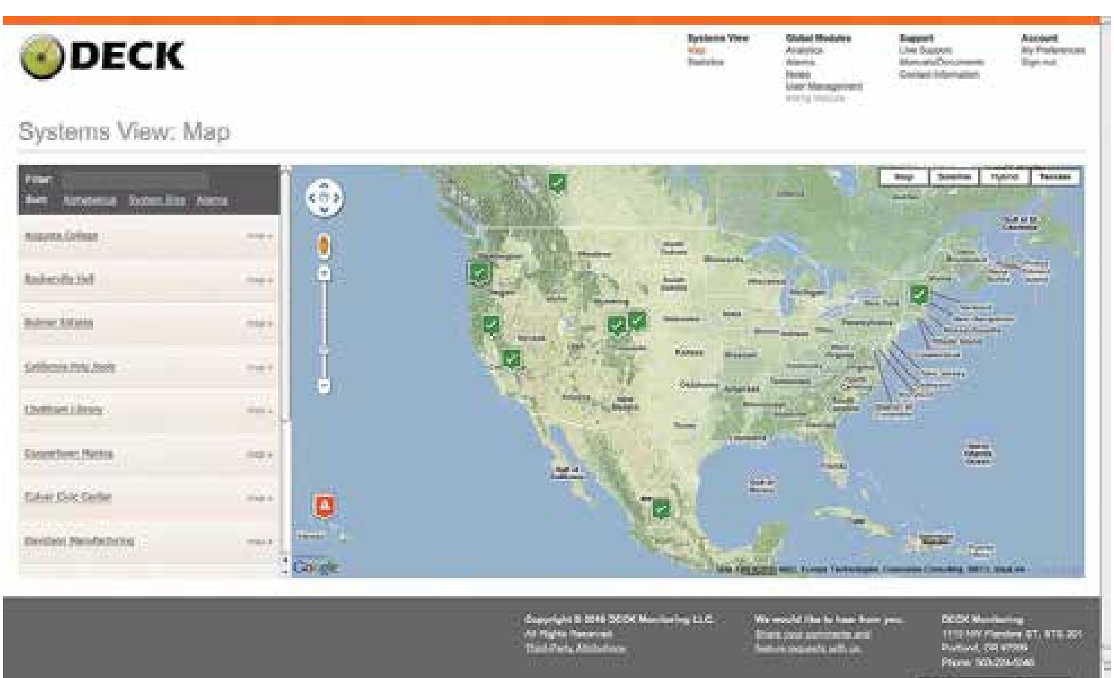
"Deciding between different levels of monitoring generally breaks down into a cost versus granularity of data argument," explains Locus Energy's De Luca. "String-level monitoring enables operators to spot a given string that may be performing below spec, but installing source-circuit combiner boxes with string-level monitoring capabilities is often prohibitively expensive."

There are, of course, always exceptions. As the value of the data being collected increases, higher degrees of granularity may be justified. In some markets the combined value of solar renewable energy credits (SRECs) and the rate of the energy being offset may warrant an investment in a very granular monitoring system. For example, if every PV-generated kilowatt-hour is valued at $0.50, then there is a significant incentive to optimize plant performance, as will be shown in a case study appearing in Part Two of this article.

According to Power-One's Tansy, "Performance monitoring at higher levels of granularity enables the operator to fine-tune plant performance at a more granular level." In addition to enabling detailed performance variance comparisons, it may also speed root-cause resolution. The faster and more accurately a problem can be identified, the faster it can be resolved.

Because the cost of data monitoring is proportional to the number of plant metrics collected and the granularity of the data, system owners want to optimize data monitoring, not just maximize it. Determining what constitutes excess data collected at too high a cost and what level of data collection provides the best return on investment is an installation- and project-specific exercise. Just keep in mind that the data you fail to collect today may turn out to be priceless tomorrow.

Freeman Corbin, director of sales at DECK Monitoring, says: "O&M service structure is the most important consideration for determining the appropriate monitoring level." After



Courtesy DECK Monitoring

Portfolio view Monitoring solutions that offer portfolio-level management are particularly useful for centralizing O&M activities for a geographically diverse range of PV projects. Administrative views, like this map view from DECK Monitoring, can enable plant operators to quickly and simultaneously evaluate system operation at multiple sites.

all, the costs associated with future O&M services are typically going to be paid by the integrator.

If a company has a large crew that performs regular on-site system checks and the cost of this service is built into the system operating costs, then inverter-level monitoring might be sufficient. Similarly, if the O&M model pays the integrator to send someone into the field to check every string manually, then there is little incentive to install a granular monitoring system.

However, as integrators install more systems and their service territory grows, centralizing O&M by using a more sophisticated monitoring system might prove to be a better option. This can allow one person at the company to monitor an entire fleet of PV systems from a single web portal. More granular monitoring data can then be used to send troubleshooting crews out with a focused agenda or maintenance schedule, which may save time and money over the life of the system.

Beware of putting systems on autopilot, though. According to Bill Brooks, principal engineer at Brooks Engineering: "Too often, system operators think that with string-level monitoring they can sit back and wait for things to go wrong. This is a flawed approach. Data monitoring systems should never take the place of regularly scheduled preventative maintenance."

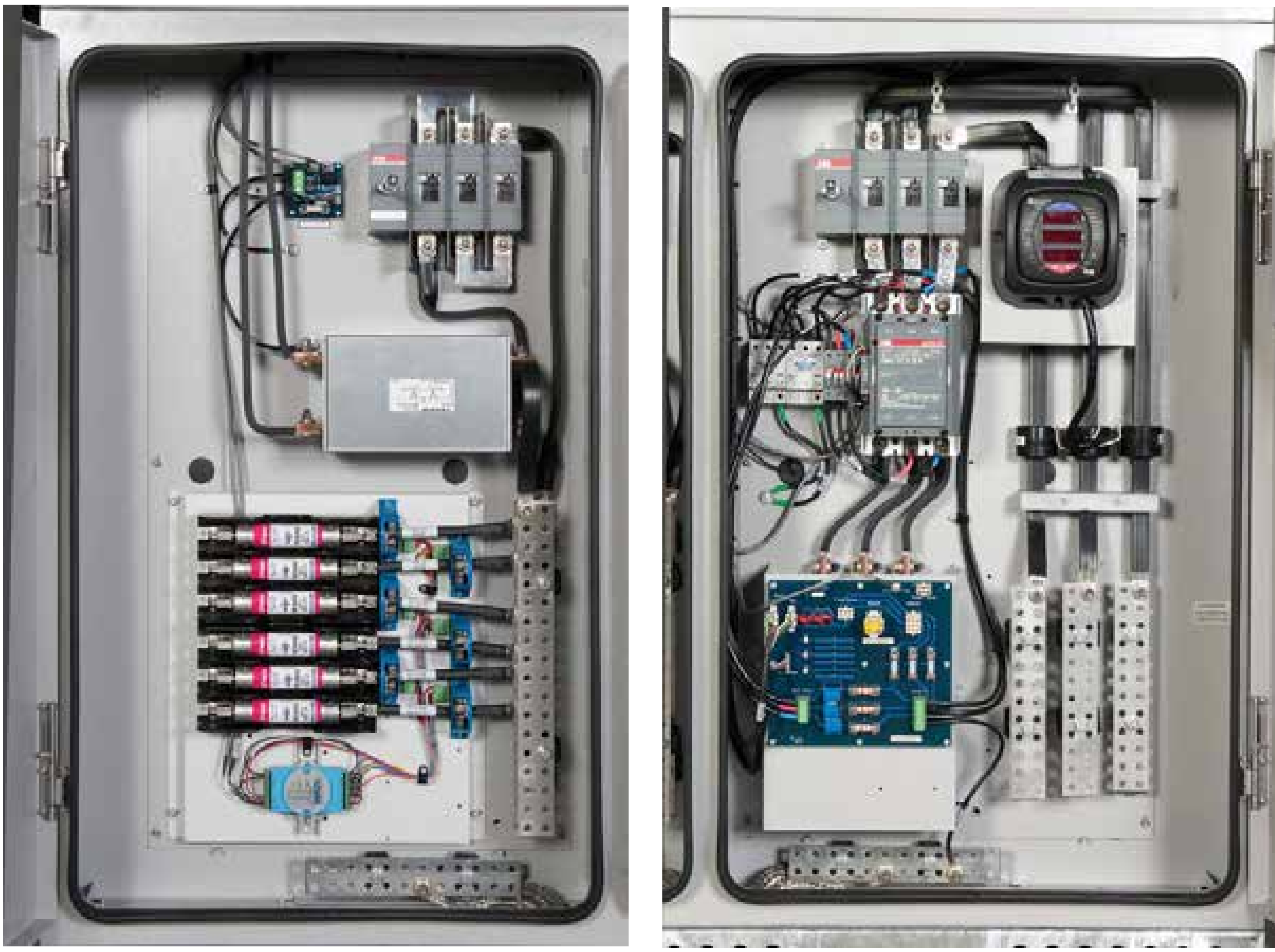
GRANULARITY PROS AND CONS

The higher the level of granularity in your monitoring system, the more complex the monitoring system becomes. If you are collecting inverter-level data and information from a single energy meter, the number of communication circuits and data collectors is relatively small and thus simple to design and implement. However, when you are collecting large amounts of string-level data, the network becomes necessarily more complex, more devices are involved and the conduit and cable schedules get larger as well.

Inverter level. Total system or inverter-level monitoring has the advantage of being the least expensive option and the least complex to install. Typically the inverter or inverters are daisy-chained with cable appropriate for an RS-485 based Modbus network to the datalogger, revenue-grade meter and weather-station hardware.

This level of monitoring provides data on total system performance only. If there is a single inverter, it is difficult to benchmark production, because there is nothing to compare inverter output against. If issues arise in a system that is monitored at the inverter level, the entire array or subarray must be examined. Another disadvantage to this monitoring scheme is that performance problems can easily go unnoticed and persist until the next scheduled maintenance interval, if not longer.

When more than one inverter is used, at least some level of performance variance analysis is possible. With multiple inverters in the system, the inverters' output power can be compared for consistency. This can reduce troubleshooting time by enabling a process of comparison and elimination.



Courtesy Advanced Energy

Inverter monitoring Central inverter manufacturers increasingly offer sophisticated data monitoring options direct from the factory. On the left, Advanced Energy's subcombiner monitoring option is shown integrated inside the fused input combiner to a PVP 100 kW inverter. On the right, optional factory-installed and tested revenue-grade metering hardware is shown at the inverter's ac output.

When many smaller-capacity inverters—single-phase string inverters, for example—are individually monitored and compared, the net effect is equivalent to combiner box output-level monitoring and may even provide string-level insight into system performance.

Combiner box output level. The next level of complexity and granularity is combiner box output-circuit monitoring, which is also referred to as *zone* or *subarray* monitoring. This level of monitoring can be accomplished in several different ways, depending upon the system configuration and the locations where measurements are taken.

The simplest way to achieve zone monitoring for commercial-scale PV systems is generally to specify subarray monitoring at a central inverter's fused input combiner. In some cases, the manufacturer offers this option.

"We currently offer system-, inverter- or subarray-level monitoring," notes Michael Zuercher-Martinson, CTO at inverter manufacturer Solectria Renewables. "Subarray monitoring comes factory-installed within the inverter and gets us 80% of the string-level monitoring benefits for 20% of the equipment cost," he continues. "No additional wiring or IT setup or configuration is required."

Alternatively, system designers can specify smart subarray combiners within the array field. These large combiner boxes are outfitted with CTs and bolt-in fuses that aggregate PV output conductors from source-circuit combiner boxes. Subarray combiners are useful on large commercial systems. For example, if a 500 kW central inverter with six 450 A fused inputs is monitored at the input combiner only, then there is very little granularity to zone monitoring. The loss of a CONTINUED ON PAGE 84

single string is very difficult, if not impossible, to detect. However, if six smart subarray combiners are specified upstream from the inverter, then the granularity of the zones being monitored can be improved until string-level resolution is achieved.

While combiner box output-level monitoring is more expensive than inverter-level monitoring, it provides much more information about the performance of the system. It improves the resolution of the data used for comparative analyses, allowing for quick baseline system performance verification. If differences are detected in combiner output circuits, troubleshooting efforts can be targeted at a much smaller section of the array.

Planning becomes extremely important when monitoring at this level, especially if communication circuits extend into the array field. Additional components are needed, such as a smart combiner box with CT equipment. A communication line needs to be run to each combiner box location, unless a wireless solution is available. Each combiner box requires its own power supply. For best results, work directly with a monitoring solutions provider on the specific design details as the project is conceived and developed.

String level. If more granular data is desired, the resolution of the data monitoring system can be extended to the level of the source circuits or module strings. Further dividing the system in this manner allows owners and operators to pinpoint performance issues and reduce on-site troubleshooting time.

The equipment necessary for this level of monitoring is very similar to that needed for smart subarray combiner monitoring. However, additional CTs are needed within the monitoring system. Instead of CTs located at the subarray level on PV output circuits, string-level monitoring requires smart source-circuit combiner boxes, which typically have a CT for every one to two source circuits.

A string-level CT unit—like the Multi Circuit DC Monitor manufactured by Ovius—typically has eight noncontact Hall Effect sensors and provides a Modbus RS-485 output for monitoring eight module strings. The units are modular in the sense that multiple CT units can be incorporated into a single enclosure for 16-, 24- or 32-circuit combiner boxes, which are available from companies like AMtec Solar and SolarBOS. The Ovius CT units require a 24 Vdc power source, which typically means that a 120 Vac circuit needs to be run to each combiner box in order to power a 120 Vac/24 Vdc power supply.

While string-level monitoring can be effective for detecting faulty equipment and low-performing modules, it also adds a great deal of complexity to the PV data CONTINUED ON PAGE 86

Courtesy AMtec Solar

String-level granularity This Prominence series smart combiner from AMtec Solar provides string-level monitoring for 16 source circuits and includes an optional wireless Modhopper.

acquisition system. For this monitoring to be effective in the long term, a thorough review of the plant is necessary during system commissioning to map each string to its corresponding sensor. Despite the best intentions of power system and data acquisition system designers, changes in the field do happen. A well-documented set of as-built drawings is crucial for troubleshooting later with this level of data analysis.

Module level. Module-level monitoring is not currently offered by independent third-party monitoring solutions providers. Rather, it is a side benefit of installing module-level power electronics: ac modules, microinverters or dc-to-dc optimizers. At present, these three technologies are rarely seen in commercial PV applications due to the economy of scale that larger string or central inverters provide.

While this level of monitoring can obviously be very effective in detecting low-performing modules, the sheer amount of data generated in a large array necessitates a computer-driven model for detecting anomalies. As with string monitoring, for the data to be useful later for troubleshooting in the field, mapping the devices to the sensors is a crucial commissioning step—one that becomes more important with each higher level of monitoring system granularity.

"The best practice that we can recommend is to make sure that the asset owner or maintenance team has a good plan for making use of the data we are providing," says Krisa of Tigo Energy. He explains: "Instrumenting a system well is just the first step. The system owners must also ensure that the organization and business processes are in place to use the data once they have it. We can help by providing the tools to manage fleets of systems and summary metrics that can mitigate the issue of having too much data. But our best customers also have the team and operational plan in place to make use of the tools that we provide."

System Implementation

In Part Two of this article, we will consider commercial PV data monitoring system selection and specification criteria in more detail. Completing a site survey is an important early step. You need to decide what data must to be collected and what web portal views are necessary. You need to provide Internet access. The location of data acquisition system components drive conduit and circuit routing. Making these design decisions early is critical, so that installation crews can efficiently execute the scope of work associated with the data monitoring system.

Special thanks to Bill Reaugh at Draker Laboratories for providing expert technical review services and input during the preparation of this article.

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Resources

Third-Party Commercial PV Monitoring Providers:

AlsoEnergy / 866.303.5668 / alsoenergy.com

ArgusON / 866.459.4103 / arguson.com

DECK Monitoring / 503.224.5546 / deckmonitoring.com

Draker Laboratories / 866.486.2717 / drakerlabs.com

Fat Spaniel (Power-One) / 408.785.5200 / fatspaniel.com

Locus Energy / 877.562.8736 / locusenergy.com

Solar-Log / 203.702.7189 / solar-log.com

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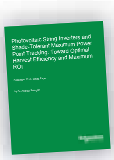

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Back-of-Module Temperature Measurement Methods

By Ryan M. Smith with Sarah Kurtz and Bill Sekulic

The accurate measurement of PV module temperature is important for tasks ranging from the determination of normal operating cell temperature (as performed by testing laboratories and manufacturers) to the performance analysis of utility-scale generation plants. Module temperature is a key input to performance models and is essential for the translation of I-V curve data to standard test conditions (STC). Unfortunately, this measurement is difficult to complete with accuracy and is highly dependent on the method by which the measurement probe is attached to the module.

In this article, we present results from a series of empirical tests at the National Renewable Energy Laboratory (NREL) that focused on the method used to attach back-of-module temperature measurement devices to a simulated PV module. The results from this evaluation provide suggested best practices for system installers and operators to successfully monitor module temperatures and to understand the implications of various attachment methods.

NEED FOR ACCURATE MEASUREMENTS

Why do module temperature measurements matter, and why should anyone be concerned with the method of attachment? The temperature of the module—specifically, the temperature of the solar cell junction—impacts the energy production of the module. Temperature coefficients are

Courtesy NREL, PIX #19403

usually stated by module manufacturers in terms of the effect of temperature on short-circuit current (α), open-circuit voltage (β) and power (γ), and may be listed in either absolute terms (amperes, volts or watts per °C) or relative terms (% per °C). As the parameter most applicable to system performance analysis, typical values of the relative temperature coefficients of power for various module technologies are listed in Table 1.

Translation equations provide you with a working knowledge of how a module behaves in differing thermal environments. Beyond that, they include temperature coefficients that are used to calculate a module's electrical characteristics at an arbitrary temperature condition using data measured at a different temperature, such as at a standard reference condition. Standard translation equations are as follows:

Using absolute temperature coefficients:

$$I_{SCcorr} = I_{SC} + \alpha(T_2 - T_1)$$
$$V_{OCcorr} = V_{OC} + \beta(T_2 - T_1)$$
$$P_{MAXcorr} = P_{MAX} + \gamma(T_2 - T_1)$$

Using relative temperature coefficients:

$$I_{SCcorr} = I_{SC} \times [1 + \alpha(T_2 - T_1)]$$
$$V_{OCcorr} = V_{OC} \times [1 + \beta(T_2 - T_1)]$$
$$P_{MAXcorr} = P_{MAX} \times [1 + \gamma(T_2 - T_1)]$$

where I_{SC} is the short-circuit current measured at temperature T_1 and I_{SCcorr} is the short-circuit current translated to temperature T_2 (see References 1 and 2). Similar definitions apply to V_{OC}, V_{OCcorr}, P_{MAX} and $P_{MAXcorr}$.

For accurate performance monitoring, modeling and assessment of warranty claims, it is important to know the module temperature coefficients and the appropriate translation of measured temperatures. System operators often use module temperature measurements, in addition to electrical and meteorological data, to commission the system and to predict the output of large-scale systems. An inaccurate measurement of module temperature, which is typically low as compared to reality, results in an overprediction of expected power output. This is due to the negative value of γ, the temperature coefficient of power, which indicates that an increase in temperature results in a decrease in power. For instance, as shown in Figure 1, a measurement that is low by 5°C may result in an overprediction of expected dc power by about 2.25%, a significant amount for large systems.

Beyond performance monitoring, module temperature may be used in degradation rate calculations for systems and modules. An erroneously low temperature measurement during the review of module I-V traces for analysis or warranty claims could trigger an unnecessary module replacement

Temperature Coefficients

Technology	TC of Power, γ (%/°C)
c-Si	-0.45
µc-Si	-0.44
a-Si (1-, 2- and 3-junction)	-0.24
CdTe	-0.29
CIGS	-0.47

Courtesy NREL (2)

Table 1 Typical relative temperature coefficients (TC) of power for various module technologies are published on manufacturer data sheets. Negative values indicate that power decreases as temperature increases.

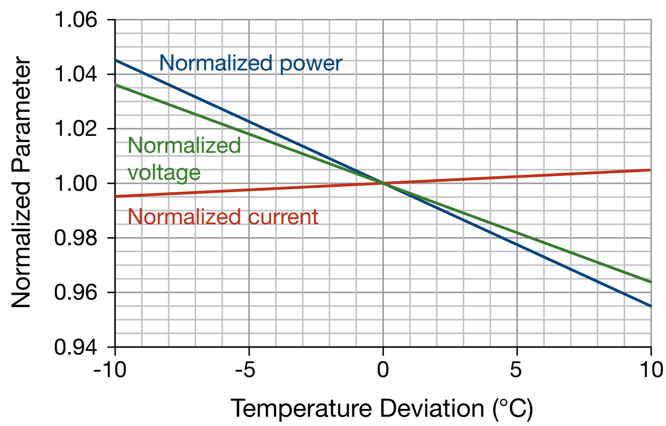


Figure 1 This plot shows the normalized, expected outputs for a system of monocrystalline silicon modules as a function of the deviation of the back-of-module temperature from reality. A low measurement results in an overprediction of power output and Voc and an underprediction of Isc. Typical relative temperature coefficients of power, current and voltage for a monocrystalline silicon module of -0.45, 0.048 and -0.36 %/°C, respectively, are assumed.

or impact other analyses. This is because comparisons are made against module STC parameters (reported at 1,000 W/m^2 irradiance, AM1.5 spectrum and 25°C module temperature) that necessitate translation of the I-V curves from the measured field conditions. Temperatures that are underreported lead to errors in calculated power when translating back to STC, potentially yielding a lower power rating.

TYPICAL ATTACHMENT METHODS

Several methods exist to measure the temperature of a module, but not all are practical for use in the field. First, an accurate measure of the average junction temperature can be obtained by measuring the open-circuit voltage of a fielded reference module. This method requires knowledge of the open-circuit voltage thermal coefficients of the cells within the module. It is arguably the most reliable method, because it represents the average junction temperature across a whole module as compared to other methods that rely on discrete measurement locations. Also, a temperature probe can be installed on the back surface of a cell prior to module encapsulation. Finally, a measurement taken on the back surface of the module can act as a proxy for the cell junction temperature. Other quantitative methods, such as the use of infrared thermography, are relegated mostly to laboratory settings and rarely make it into the field for long-term monitoring.

Unfortunately, commercially available modules generally do not offer the capability to measure the junction temperature using built-in measurement devices, and the use of fielded reference modules maintained at V_{oc} is not common. The vast majority of applications require the attachment of a measurement device to the backsheet or substrate of the module. It is important to note that module backsheet measurements are generally lower than the actual junction temperature. This is because of the insulating properties of the encapsulant, which is often EVA, and the backsheet, often composed of multilayer polyesters. Researchers studying module nominal operating cell temperatures (NOCT) have calculated a temperature drop of between 1° and 2°C between the junction and the substrate (see Reference 3).

We conducted a survey of utility- and commercial-scale system installers and operators to gain insight into some of the typical methods for attaching temperature measurement probes to the backs of modules. Common methods include the use of beaded or thin-film thermocouples attached with polyimide or polyester tape, or a quick-setting adhesive such as epoxy or silicone. When installers were asked if they followed specific attachment procedures, including surface preparation, the general consensus was "no," which became the impetus for this work. In the case of polyimide tape, the quality of the attachment can significantly degrade after only a few years of field exposure. Epoxies CONTINUED ON PAGE 94

can embrittle due to UV exposure, and silicones can detach if the attachment surface is not adequately cleaned.

Poor attachment at the beginning of monitoring, such as during commissioning, may result in a lower power rating. However, poor surface preparation coupled with a less-than-ideal attachment method can pose longer-term problems, including drift and range spread. Drift becomes a concern when analyses that use present-day measurements are compared against historical measurements or analyses. The performance of a system may be viewed as excessively degraded when in reality the apparent degradation is caused by an attachment-induced measurement drift. In addition to drift, range spread may be seen in analyses as inconsistent results. This is due to the increased influence of wind and local environmental parameters on measurement devices with poor thermal contact to the module backsheet.

In an ideal circumstance, heat is primarily conducted from the module to the measurement device. The two other heat transfer mechanisms that have an influence on the measurement—radiation and convection—are significantly outweighed by conduction. However, when the sensor is in poor thermal contact with the module, conduction is inhibited and convective cooling becomes significant. This results in a spread in the range of measurements. Even lower apparent temperatures are recorded when wind velocities increase. In addition, the presence of insulation around the sensor and/or a difference in the emissivity of the sensor and the module can change the module temperature. In that case, the sensor may give an accurate measurement of the actual localized temperature of that module, but it does not represent the average temperature of modules that do not have the sensor applied. (These effects are beyond the scope of this article.)

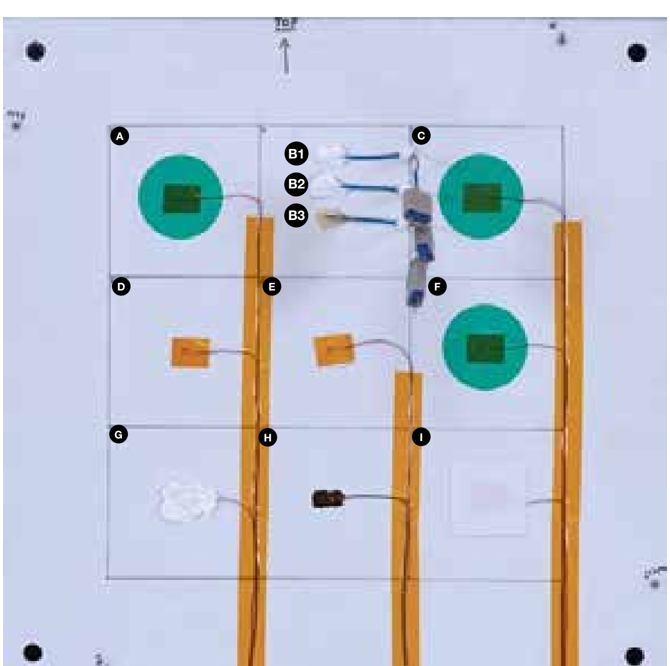
PROBE ATTACHMENT TESTS AT NREL

The focus of this test series was to review attachment methods, not to evaluate the use of different sensor technologies such as thermocouples, thermistors and resistance temperature detection. For this work, we used only type-T thermocouples.

To determine if common attachment methods are adequate for the measurement of back-of-module temperatures, an 18-by-18-by-0.5-inch aluminum plate was prepared with a black anodized front surface and an EVA/polyester lamination on the rear surface. We used type-T thermocouple probes, installed at half of the plate thickness on all four sides, to determine the average bulk-plate temperature throughout the study. The plate was thermally isolated from the mounting frame during testing. The completed test setup was mounted at 180° azimuth with a 40° tilt angle (see photo on p. 90).

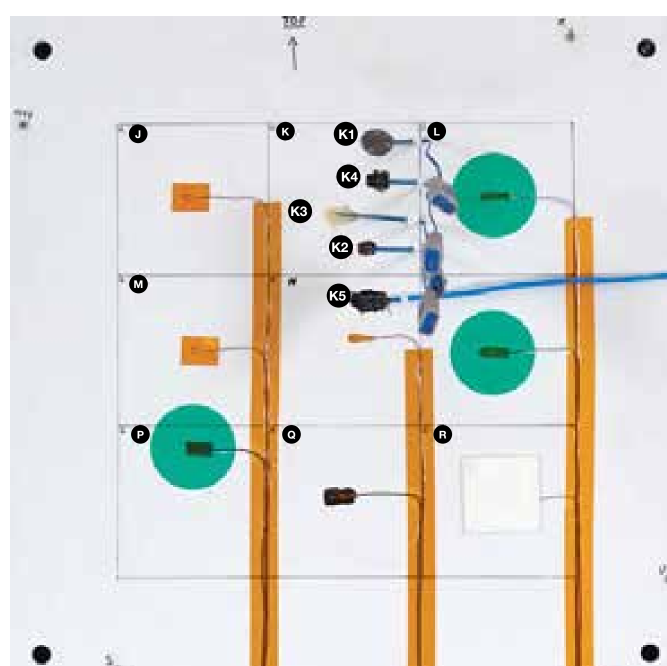
Two rounds of tests were conducted, accounting for a total of 20 different attachment/thermocouple combinations. Three attachments from Round 1 were continued in Round 2. The details of both rounds CONTINUED ON PAGE 100

Figure 2 Overview of the Round 1 attachments. See Table 2 (p. 96) for details of each attachment method.



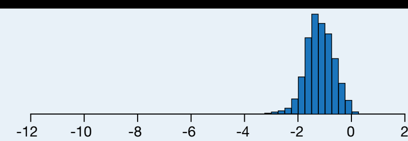
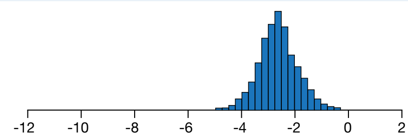
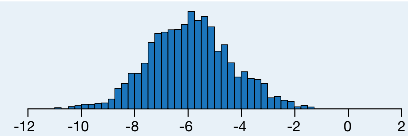
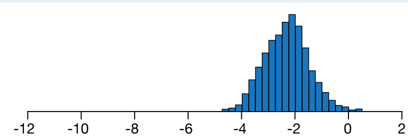
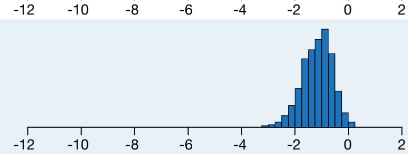
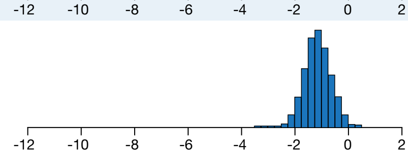
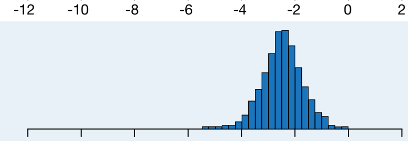
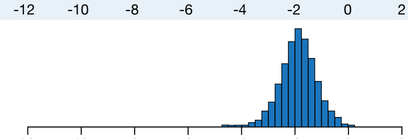
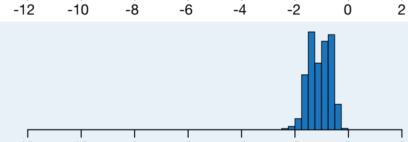
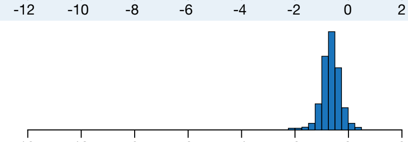
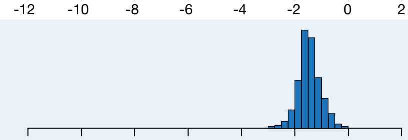
Courtesy NREL, PIX #19404

Figure 3 Overview of the Round 2 attachments. See Table 3 (p. 98) for details of each attachment method.



Courtesy NREL, PIX #19405

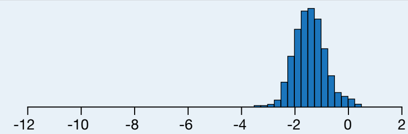
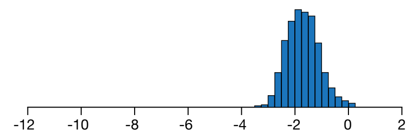
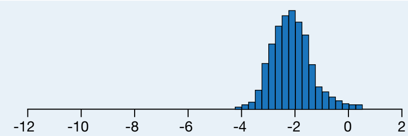
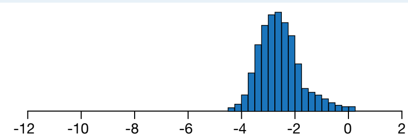
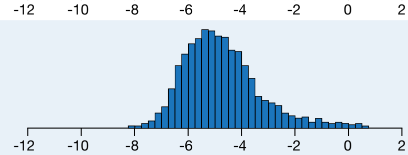
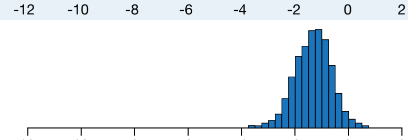
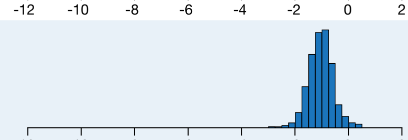
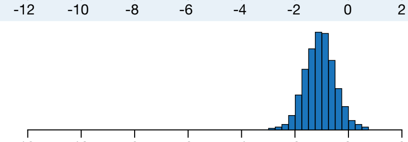
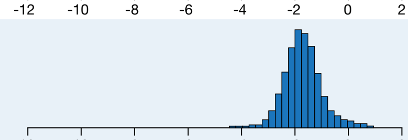
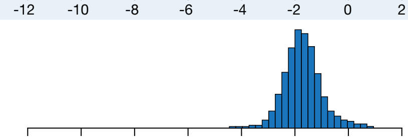
Table 2: Round 1 Test Results

Position	Details	R/P*	Distribution 750–1,050 W/m^2 (°C)	$\overline{\Delta T}_{sensor}$ (°C)	$\sigma_{\Delta T_{sensor}}$ (°C)
A	Thin-film thermocouple, type-T; thin silicone adhesive with round polyester tape overlay	R		-1.18	0.47
B1	Twisted and soldered thermocouple, type-T; silicone adhesive with tip of thermocouple pressed against backsheet during cure	R		-2.63	0.67
B2	Twisted and soldered thermocouple, type-T; silicone adhesive with tip of thermocouple pressed against backsheet during cure* **Intentional 80% delamination from backsheet after cure*	R		-5.90	1.52
B3	Twisted and soldered thermocouple, type-T; two-part unfilled epoxy adhesive with tip of thermocouple pressed against backsheet during cure (cure time ~5 minutes)	P		-2.33	0.81
C	Thin-film thermocouple, type-T; round polyester tape overlay attachment with no adhesive	R		-1.16	0.54
D	Thin-film thermocouple, type-T; thin silicone adhesive with no additional overlay	R		-1.13	0.48
E	Thin-film thermocouple, type-T; thick silicone adhesive (~4 mm) with no additional overlay	R		-2.47	0.70
F	Thin-film thermocouple, type-T; round polyester tape overlay attachment with thermal compound	R		-1.87	0.63
G	Thin-film thermocouple, type-T; thin silicone adhesive with thick (~4 mm) silicone overlay	R		-1.06	0.39
H	Thin-film thermocouple, type-T; thin, two-part thermally conductive epoxy adhesive with no overlay (cure time ~48 hours)	P		-0.64	0.30
I	Thin-film thermocouple, type-T; 0.85 mm closed-cell foam tape overlay with no adhesive	R		-1.46	0.39

* R= removable attachment method; P= permanent attachment method

Courtesy NREL

Table 3: Round 2 Test Results

Position	Details	R/P*	Distribution 750–1,050 W/m^2 (°C)	$\overline{\Delta T}_{sensor}$ (°C)	$\sigma_{\Delta T_{sensor}}$ (°C)
J	Thin-film thermocouple, type-T; moderate-thickness silicone adhesive with no overlay	R		-1.41	0.55
K1	Twisted and soldered thermocouple, type-T; steel-filled, two-part semi-solid epoxy with tip of thermocouple pressed against backsheet during cure (cure time ~15 minutes)	P		-1.70	0.58
K2	Twisted and soldered thermocouple, type-T; metal-filled, two-part liquid epoxy with tip of thermocouple pressed against backsheet during cure (cure time ~60 minutes)	P		-2.15	0.70
K4	Twisted and soldered thermocouple, type-T; two-part thermally conductive epoxy adhesive (cure time ~48 hours)	P		-2.58	0.73
K5	Crimped bead thermocouple, type-T; two-part thermally conductive epoxy adhesive (cure time ~48 hours)	P		-4.79	1.33
L	Thin-film thermocouple, type-T, trimmed to within 2 mm of tip; round polyester tape overlay attachment with no adhesive	R		-1.32	0.63
N	Thin-film thermocouple, type-T, trimmed to within 2 mm of tip; thin silicone adhesive with no additional overlay	R		-1.04	0.43
O	Thin-film thermocouple, type-T, trimmed to within 2 mm of tip; round polyester tape overlay attachment with thermal compound	R		-1.06	0.53
P	Thin-film thermocouple, type-T; round polyester tape overlay attachment with thermal compound* **Similar to test "O" but with smaller gauge (thicker) thermocouple wire*	R		-1.70	0.66
R	Thin-film thermocouple, type-T; 1.7 mm closed-cell foam tape overlay with no adhesive	R		-1.29	0.33

* R= removable attachment method; P= permanent attachment method

Courtesy NREL

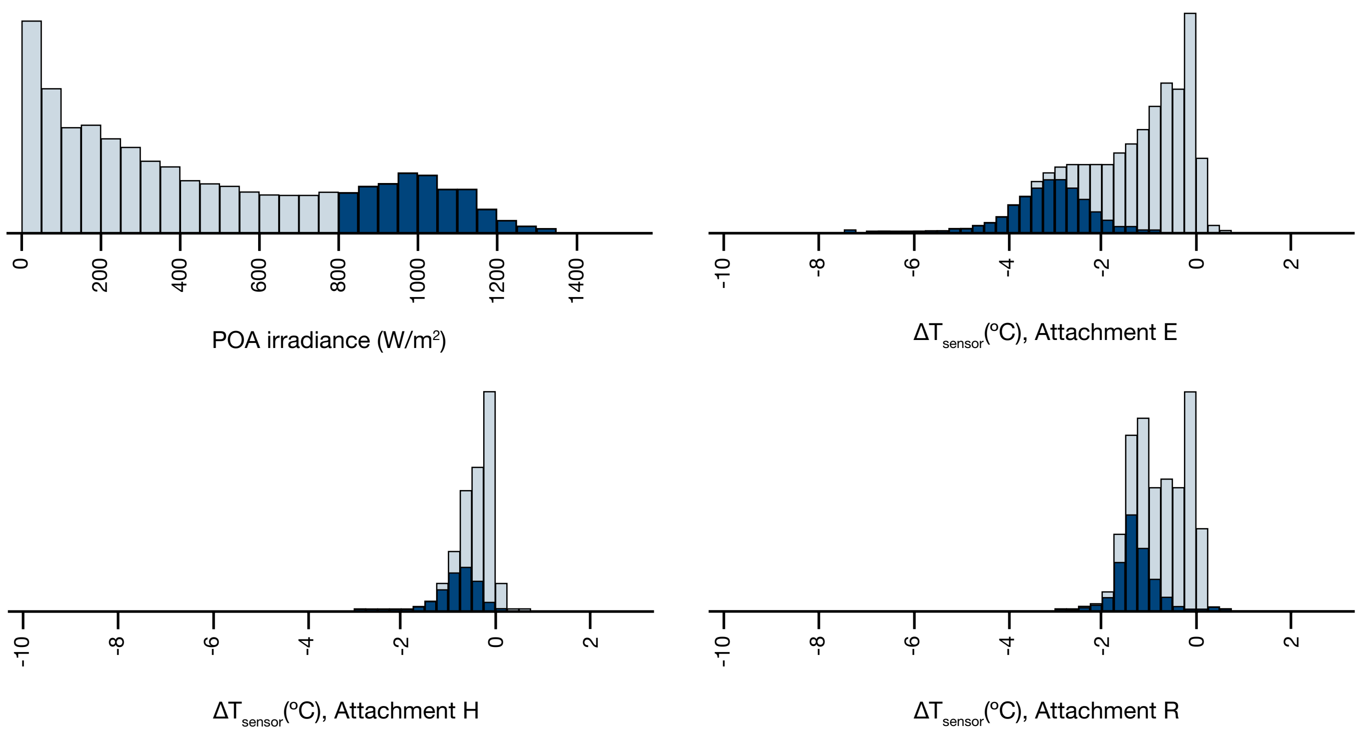


Figure 4 The changes in the distribution of the mean deviation from bulk-plate temperature, ΔT_{sensor}, due to plane-of-array irradiance binning are shown. The light blue sections show deviations for irradiances between 5 and 800 W/m². Dark blue sections show deviations for all irradiances above 800 W/m². Note the significance of this threshold on all sensor types.

of tests, including the removable or permanent nature of the attachment method, are described in Table 2 (p. 96) and Table 3 (p. 98). The backsheet was cleaned with 70% isopropyl alcohol on lint-free wipes and dried before attaching the test devices. Unless noted otherwise in the tables, the thermocouples were mounted in the as-received condition from the manufacturer. We attempted to replicate both effective and poor mounting practices during testing. Poor attachment methods have a significantly detrimental effect on the measurement of module backsheet temperatures.

Before each round of testing, the test plate was installed outdoors on the test rack and temperatures were monitored for each test sensor and for the four bulk-plate measurement probes. Because of the inherent variation in measurements from type-T thermocouples (as received, a probe is usually ±1°C), offsets were applied iteratively to each sensor within the datalogger code to minimize the variation between sensors during calm, nighttime conditions (2am to 4am, wind velocity <1 m/s, no measurable irradiance). This method effectively acts as a field calibration. Through four iterations of this process, the variation between the four bulk-plate temperature measurements was limited to <0.3°C, and the variation between the test sensors was <0.8°C.

Round 1 was completed in April 2011, and Round 2 was completed in June 2011. Measurements of the test sensor temperatures and environmental parameters were captured every 5 seconds, 24 hours per day, for 14 continuous days in each round of testing. This resulted in over 480,000 measurements from which to perform analyses. Over the course of testing, wind speeds reached up to 16 m/s and ambient temperatures ranged from −1°C to 35°C. Bulk-plate temperatures ranged between −1°C and 55°C.

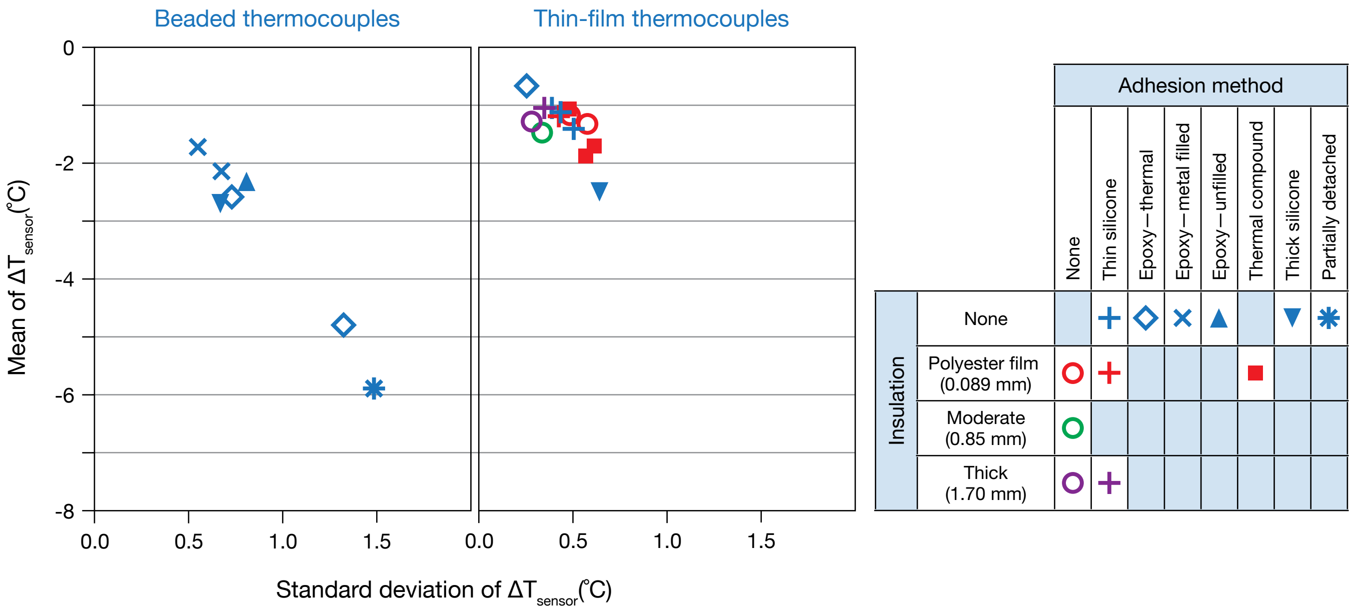
TEST RESULTS

The most appropriate way to review the results was to limit the data set to daytime conditions (plane-of-array irradiance >5 W/m²) when the range in the bulk-plate temperature was small (<1°C), eliminating times of rapid heating or cooling. We then calculated the deviation of each instantaneous measurement from the average bulk-plate temperature as follows:

$$\Delta T_{sensor} = T_{sensor} - \overline{T_{bulk\ plate}}$$

Negative values of ΔT_{sensor} indicate that a sensor measured a lower temperature than the bulk plate average. In the following discussion, the results of this simple calculation are referred to as *deviations.*

A review of the distribution of the deviations for measurements taken above 5 W/m² reveals CONTINUED ON PAGE 102



Courtesy NREL

Figure 5 Mean deviation from bulk-plate temperature, ΔT_{sensor}, versus the standard deviation of ΔT_{sensor} for plane-of-array irradiances between 750 and 1,050 W/m^2 are shown. Symbol shapes denote thermocouple adhesion method and symbol color corresponds to the level of insulation.

that the shapes of the distributions of ΔT_{sensor} vary significantly from test to test. Temperature measurements on modules, however, are of increased significance when the incident irradiance is above 800 W/m^2 because of NOCT and STC rating conditions. Figure 4 (p. 100) shows the effect of removing deviations for irradiances below 800 W/m^2. The full-range distributions (>5 W/m^2) for three example attachments have drastically different shapes, but all tend towards normal distributions when the irradiance is limited by this lower threshold. This is the case across all tested attachment methods. As the threshold increases to higher irradiances, the mean deviation for most attachments stabilizes near 1° to 2°C loss, as expected from heat transfer calculations. To maintain consistency with NOCT and STC rating conditions, data was limited to measurements captured at irradiances between 750 and 1,050 W/m^2. In describing what is desired in an attachment method, a measurement should be as close to the actual junction temperature as possible and, more importantly, track closely with changes in the junction temperature.

So what metrics should be used to make a judgment between attachment methods, given the stated criteria? The mean deviation from the bulk-plate temperature, $\overline{\Delta T}_{sensor}$, describes the average temperature difference between the bulk-plate temperature and the sensor. The standard deviation of the distribution, $\sigma_{\Delta T_{sensor}}$, describes the variation of the measurements from the distribution's mean. A low standard deviation describes a distribution for which more of the ΔT_{sensor} values are close to the mean deviation, whereas a high standard deviation describes a wider distribution with points spread over a larger range of ΔT_{sensor} values. Combined, the mean and standard deviations provide sufficient information from which to begin evaluating attachment methods by general characteristics such as adhesion method, insulation thickness and thermocouple style, as shown in Figure 5. In addition, Tables 2 and 3 include the values of $\overline{\Delta T}_{sensor}$ and $\sigma_{\Delta T_{sensor}}$ for each attachment method.

We can make several key observations from Figure 5. First, as a general rule, thin-film style thermocouples perform better than beaded thermocouples. The worst performance was for the partially detached (B2) and high-surface-area beaded thermocouples using thermal epoxy (K5). This is indicated by the high $\overline{\Delta T}_{sensor}$ and high $\sigma_{\Delta T_{sensor}}$ values for these attachments and emphasizes the importance of effective adhesion and clean installation methods. If it is necessary to employ a beaded thermocouple, then the use of a metal-filled epoxy yields the best performance. Second, the adhesion method and insulation thickness are equally important in building a successful attachment. In the case of thin-film thermocouples, attachment H appears to have the lowest mean deviation and standard deviation. This may be an artifact—it remains a good attachment method but may show a systematic error of up to 1°C. The addition of insulation does show an improvement over uninsulated sensors, with the thick (1.7 mm) layers exhibiting slightly lower $\overline{\Delta T}_{sensor}$ and high $\sigma_{\Delta T_{sensor}}$ values as compared to moderate and thin insulation attachments. However, adhesion with a thin layer of silicone produces high-quality CONTINUED ON PAGE 104

results regardless of the level of insulation. The use of a thicker adhesion layer (attachment G) results in decreased performance. In general, the use of thermal compound with thin insulation does not provide results as good as using either thin silicone or no adhesion layer. Not all attachment methods were included in these tests, such as substantially thicker insulation layers or combinations of adhesions and insulation thicknesses, but it is our intention to explore these attachments in the future.

BEST PRACTICES

Based on the experience of the NREL PV Reliability Group and the results of the described tests, we recommend the following best practices.

During planning, deployment and commissioning:

- Minimize the surface area of attachments and choose attachment methods that minimize the mean deviation.
- Install multiple temperature measurement probes using the same attachment method. This consistency allows for comparisons between sensors and can help differentiate results from a drifting or failing sensor from actual system performance degradation. The mounting locations should be similar.
- Plan to use the calm, zero-irradiance technique to develop offsets for the sensors. This reduces the uncertainty between the sensors and allows for improved comparisons. However, since a reference temperature from which to make adjustments is not always available, be careful when applying any offsets greater than 0.5°C. If a more accurate measurement set is desired, then the laboratory calibration of at least one of the sensors before installation is recommended; the offsets would therefore be applied to the uncalibrated sensor(s).

During attachment:

- Before attaching any sensor, clean and dry the module backsheet with a solvent that does not leave a residue. In our experience, 70% isopropyl alcohol on lint-free wipes is effective. Even small amounts of dirt or dust decrease the effectiveness of any attachment method.
- Keep all adhesive layers as thin as possible to improve thermal contact with the module backsheet. Do not allow adhesives to spread beyond the surface area of thin-film devices. This is especially important for thermal epoxies.
- Permanent attachments are most appropriate when modules are to be deployed long-term in the field. If using thermally conductive epoxies, you must be fully cognizant of their cure times. Secure the sensor and allow the attachment to cure for a few days to prevent movement.
- Reasonable levels of insulation may improve measurement performance, but the effect of excessive insulation is not yet characterized.
- Provide strain relief near the sensor attachment point to limit pulling on the sensor element.

During maintenance:

- Inspect temperature sensor attachments during routine maintenance. This is especially important for nonpermanent attachments that may pull loose or degrade over time.
- Replace removable sensor attachments (primarily tape) periodically and check for damage to sensing elements.

We intend to continue this work and expand on the attachment types and experiment durations. Please contact us with suggestions for additional experiments to benefit the photovoltaic community at large.

We would like to thank Dirk Jordan for discussions surrounding this project, Adam Stokes for assistance in summarizing manufacturer data sheets, and L. Li, J. Wohlgemuth and C. Deline for reviewing this article. This work was supported by the U.S. Department of Energy under Contact No. DE-AC36-08-GO28308 with the National Renewable Energy Laboratory.

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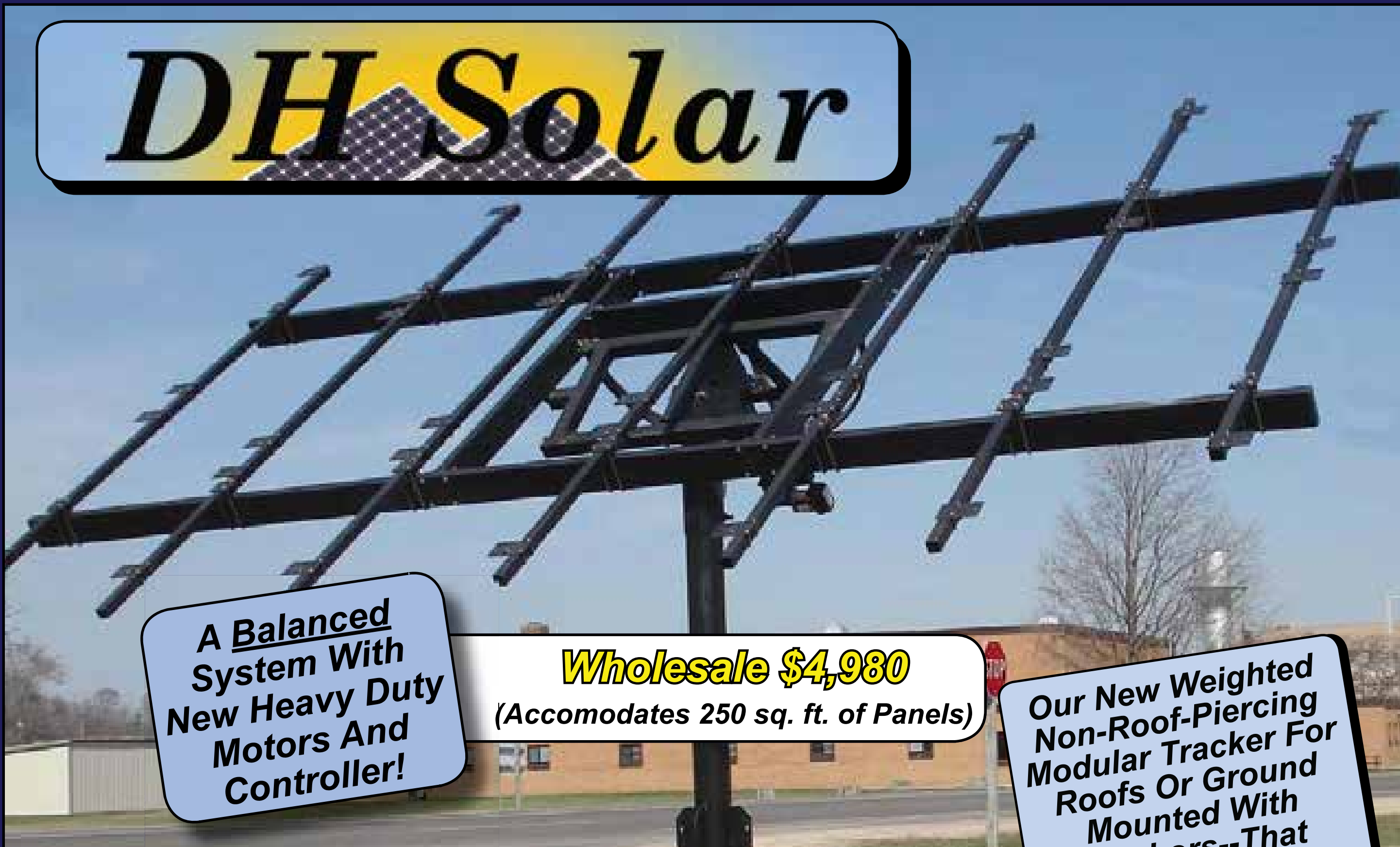

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Implemen

nting a Successful Safety Program

By Karl Riedlinger

Courtesy Cupertino Electric

Creating and maintaining a safe work environment is a legal mandate, regardless of the size of the company performing the work or the size of the project being built. Compliance requires an effective safety program.

Are you working safely? The answer to this important and seemingly simple question is seldom a straightforward “yes” or “no.” One complicating factor is that too often the decision about what constitutes “working safely” is left to a subjective personal assessment of the hazards present, balanced against an individual’s personal comfort level. However, often what feels safe for one person may not feel safe for another.

To ensure worker safety, you need to systematically assess and address hazards by following clearly defined and detailed safety procedures. Objectively evaluating whether you are working safely is no easy task. Inherent in the simple question is a larger question, one that is more complex and nuanced: Are you providing the training, equipment, policies and leadership that your installers need to work safely and in compliance with the law, while ensuring that they follow the policies designed to keep them working at the highest levels of safety?

In this article, I discuss the fundamental elements of a successful safety program for solar installation companies—elements that are essential to keeping your workers safe. I show that creating and maintaining a safe work environment is a deliberate and ongoing process. Implementing a successful safety program requires buy-in from everyone—from the executive team down to the crew on the roof. Program guidelines need to be clearly documented and published. Regular training must be provided. Standards and procedures need to be reviewed and updated frequently. Compliance with established standards needs to be monitored and enforced at all times. The burden of providing the policies, training resources, safety equipment and safety management falls on the employer, while obeying the laws and polices set forth are the workers' responsibility. Employees and management must work together to keep the workplace safe.

WORKING SAFELY IS THE LAW

Anyone who has installed PV or solar thermal systems is well aware of the many dangers involved. These include working at a height that exposes you to fall hazards, working on electrical circuits with electrocution and arc-flash hazards; working in hot climates in direct sunlight; using power tools and heavy equipment; performing strenuous physical tasks such as heavy lifting; operating motor vehicles; working in confined spaces; and being exposed to respiratory hazards. These and many other activities present direct hazards to installers and other personnel. Hazards are even present in the warehouse or office.

When viewing your company's myriad daily activities through the microscope of applicable regulations, maintaining a safe environment in which work can be performed with a minimum of interference and expense can seem daunting. Nevertheless, this is a challenge you must meet, regardless of the size of your company or of the projects you build.

The most widespread workplace safety standards are those defined by the Occupational Safety and Health Administration (OSHA).

OSHA. Established by the US Congress in 1970 as part of the Department of Labor, OSHA is responsible for creating the laws that govern worker safety for private-sector employees in all 50 states and other US jurisdictions. The General Duty Clause of the Occupational Safety and Health Act requires that employers keep their workplace free of serious, recognized hazards and that employees follow "all rules, regulations and orders issued pursuant to this Act." The rules designed to protect workers from hazards are described in four OSHA standards: general industry, agriculture, maritime operations and construction. In addition to setting and enforcing safety standards, OSHA's mission includes training, outreach, education and assistance.

At first glance, the voluminous OSHA standards can seem incomprehensible—nonetheless, you must take the time to understand them. Knowing where to look for the information you need is generally half the battle. The Federal Occupational Safety and Health (OSH) plan governs about half the US; meanwhile, 25 states have implemented State OSH plans, as shown in Figure 1. CONTINUED ON PAGE 112

Figure 1 OSHA requires states to set job safety and health standards that are at least as effective as comparable federal standards. However, states have the option to establish more restrictive rules. The Federal Occupational Safety and Health (OSH) plan governs about half of the US. Currently, 25 states have implemented distinct OSH plans, as indicated in green.

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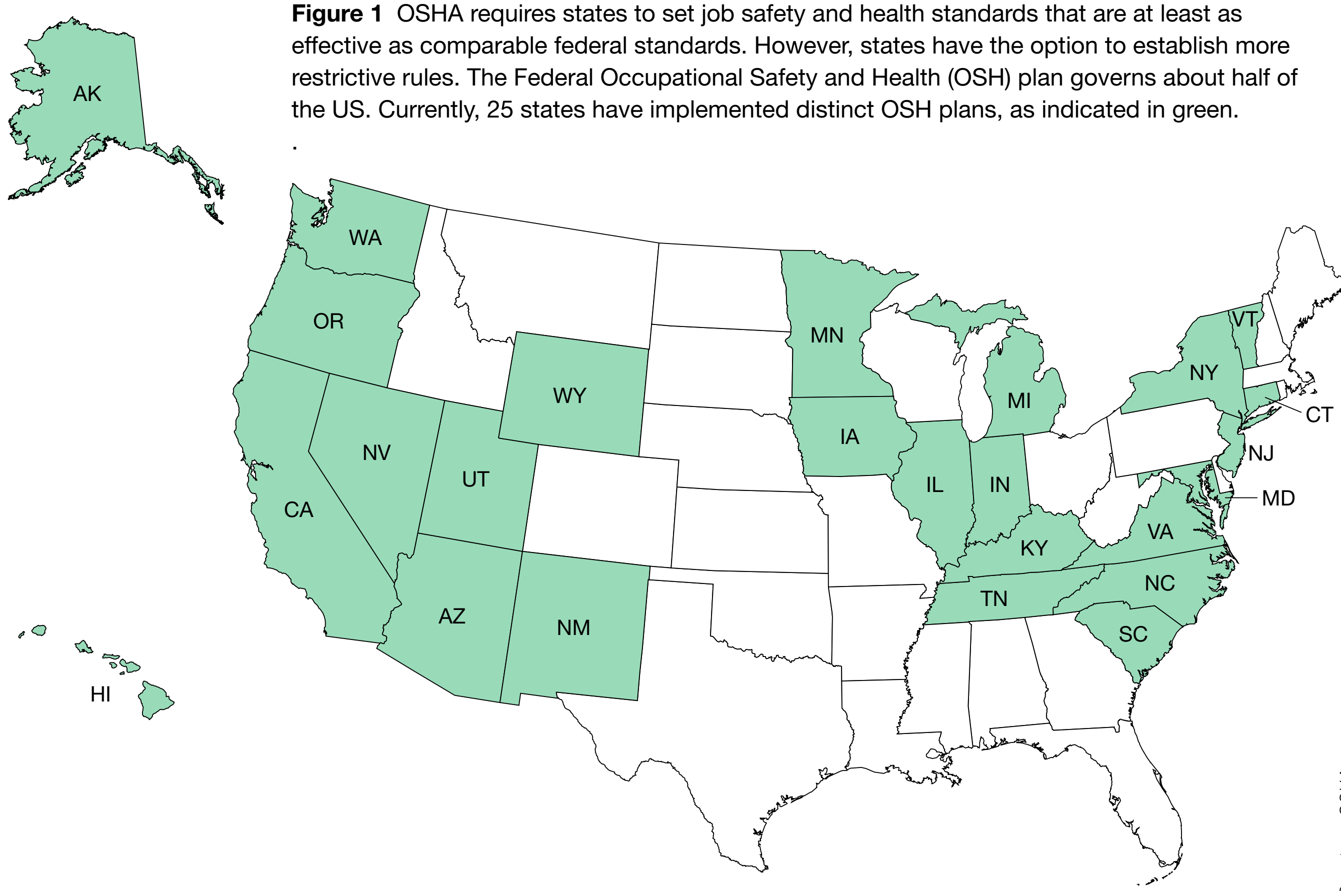

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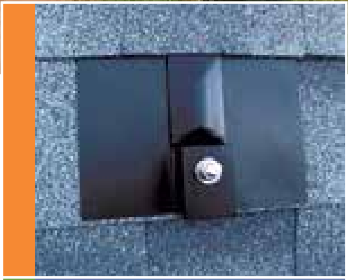

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Growing workforce There is a constant influx of new workers to the industry, some of whom are entering the construction industry for the first time. All these new workers need to be properly trained so that they can perform their work safely and in compliance.

Since OSHA requires states to set job safety and health standards that are at least as effective as comparable federal standards, many states adopt policies that are identical to the federal ones. However, states do have the option to set standards covering hazards not addressed at the federal level or to establish more restrictive rules.

Once you know whether you are working under federal regulations or a State OSH plan, the next thing to determine is the applicable OSHA standard. This determination is made based on the work being performed and who is performing it. For example, the OSHA standard that applies to PV or solar thermal installation is the standard written specifically for the construction industry. However, if manufacturing or office work is being performed, then the OSHA standard written for general industry applies.

Navigating different OSH plans can be difficult for multistate employers. Often the best solution is to adopt the most restrictive jurisdictional rules and apply these universally as company policy. This is preferable to having policies that vary state by state and can confuse travelling workers.

It is good practice to have ready access to applicable OSHA standards to clarify what you can and cannot do when writing policies or mitigating safety hazards. All of the Federal and most State OSH regulations are available online or can be bought in book form for easy reference. OSHA also has a variety of educational materials and electronic tools available on its website (see Resources), including pages on safety and health topics, safety fact sheets, videos and other resources. An extensive online publication library is available to help employers and workers identify job hazards and develop mitigation strategies.

If you have identified the OSHA plans and standards that apply to your situation and still have questions, simply ask OSHA for help. If this sounds counterintuitive, you are probably not aware of the programs and services that OSHA offers employers, including free confidential advice. You absolutely can contact OSHA with questions without worrying about getting a citation. Your primary resources are OSHA's compliance assistance specialists, who are located throughout the country and can be reached through local OSHA offices. Further, if yours is a small business—with fewer than 250 workers at a site and no more than 500 employees nationwide—OSHA provides a free on-site consultation service. Through these consultation programs, you can get clarification on OSHA rules and regulations or even have a compliance specialist come to your jobsite and provide free advice without fear of reprisal.

Industry compliance. US worker safety laws are clear about requiring workplaces to be OSHA compliant. Unfortunately, it does not take Sherlock Holmes to uncover examples of less-than-stellar worker safety practices taking place in the solar industry today. Magazine and newspaper articles, promotional photographs, advertisements, television coverage and even corporate websites routinely show workers on rooftops with a complete lack of fall protection. When something as basic as fall protection is being neglected, generally a multitude of other deficiencies are also present.

This is a disturbing public image for an industry that is being closely monitored by lawmakers, regulatory bodies, insurance companies and a host of skeptics. It is not an exaggeration to say that the continued growth of the solar industry is at stake. The policies and general goodwill that help drive growth could disappear if we as an industry behave irresponsibly by ignoring established worker safety laws and regulations.

The growth of the solar industry is both an opportunity and a challenge. There is a constant influx of new workers, some of whom are entering the construction CONTINUED ON PAGE 114

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Hazard elimination Safety program managers should always look for ways to eliminate hazards whenever possible. For example, guard-rail systems provide a higher level of worker protection than more basic warning line systems.

field for the first time. New companies are being formed from scratch, while existing contractors are breaking into the solar field from other trades. All these new workers need to be properly trained and equipped so that they can perform their work safely and in compliance. If this training happens before bad habits are allowed to develop, it will be a boon to the industry in the long run. If not, there may be an accident waiting to happen.

While some members of the public hold a negative image of OSHA as an institution—perhaps grumbling that its only purpose is to put overly restrictive rules in place—it is very important that you not let this opinion take root in your workforce. You need to cultivate a positive image of OSHA in which the organization is seen as a resource and a repository of knowledge about how to maintain a safe workplace and keep workers healthy. At the same time, you need to emphasize that disregard for safety laws can have serious consequences.

ELEMENTS OF A SUCCESSFUL SAFETY PROGRAM

The goal of everyone in the industry—from the installers on the roof to the executives in the boardroom—should be to make sure that workers get home safely every night. The only way to accomplish this is to establish a comprehensive safety program. A good program should eliminate subjectivity, ambiguity and uncertainty about the proper response to common workplace hazards, as well as educate workers about what to do when faced with unexpected or new hazards.

Implementing a safety program requires commitment and leadership. A structure needs to be in place, with established roles and responsibilities. Employees must learn how to identify and mitigate hazards, as well as how to properly use the safety equipment provided—and in some cases, they must be certified to do so. In addition to documented policies and procedures, there are administrative requirements like documentation and record keeping. Management also needs to provide oversight and enforcement, including a feedback loop to ensure constant improvement.

Safety starts at the top. Unless safety has the full backing of management, it is a challenge to get the resources needed to set up and manage a program. Implementing a safety program can involve upfront costs, such as hardware purchases and personnel training, as well as ongoing costs, including equipment maintenance, continuing education and program monitoring and administration. These costs should be seen as a basic recurring expense of doing business where safety is a cornerstone of operations. It is easy to justify these costs when it is clear that they reduce workplace injuries and keep the company OSHA-compliant.

Ideally, upper management takes a leadership role in promoting a safe working environment. Safety needs to be a priority on par with competing interests like installation speed and cost. While the benefits of investing in a robust safety program are not immediately evident on the balance sheet, the costs associated with a serious workplace injury can have far-reaching effects on the bottom line and on worker morale.

Safety first. Workplace safety should not begin when employees are confronted with a hazardous situation. Proper planning, training and well-documented safety policies should be in place and adhered to so that hazards are mitigated before anyone is put in harm's way.

On a corporate level, abiding by the safety-first principle starts with having a safety program in place. Once the structure is established, workers need to be properly trained and equipped to work safely.

Jobsite safety considerations need to be included in the site analysis, job bidding and system design processes. Because engineering controls are a more effective way to keep workers safe than using personal protective equipment (PPE), system designers and engineers should CONTINUED ON PAGE 116

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be looking for ways to eliminate hazards wherever possible when designing the system.

As an industry, we need to abide by the safety-first principle. The cost of keeping workers healthy and safe needs to be factored in when we bid on a job. The value of keeping workers safe is a benefit that we can sell to potential clients. Safety cannot be viewed as an optional job cost; it is not something that we can afford to cut during a competitive bidding process.

Cultivate a culture of safety. A culture of safety must be present in all areas of the workplace—from the warehouse to the roof and everywhere in between. It sends mixed messages if field crews are expected to behave a certain way on the jobsite, but allowed to revert to unsafe behavior at the office.

For a culture of safety to flourish, you must have buy-in from all employees. Entrenched patterns of behavior can present daunting obstacles to program acceptance. Changing the behavior of individuals who learned to practice their trade while working under very lax safety rules can be challenging. These individuals may be comfortable with the status quo, may bristle at new or increased safety measures or may try to revert to their previous ways of working. When they are confronted about their lack of compliance, you often hear responses such as, "This is how I've done CONTINUED ON PAGE 118

Shawn Schreiner

Safety equipment Personal protective and electrical safety gear needs to be accepted as a fundamental cost of doing business. Consider assigning PPE directly to individual workers, as ownership implies accountability.


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it all my life and I've been fine," or "I don't need any [insert safety measure here]. That just gets in my way."

When an individual chooses to ignore safety policies, it puts you and your other workers in a difficult position. It can be hard to convince someone with years of experience that they need to do things differently for the sake of the company. The best strategy for all workers is to be vocal in support of company safety policies, set a good example, keep an eye out for coworkers and encourage everyone to work safely.

Certification Safety certifications are required to operate specific equipment and to perform certain tasks. Copies of valid certifications should be kept on file and expiration dates should be tracked.

Courtesy Cupertino Electric

If an individual refuses to follow documented safety policies, the best course of action may be for his or her peers to speak to their manager. Disregard for company policies should not be tolerated. Speaking up before an accident happens is certainly preferable to answering questions afterward about why you did not speak up earlier. Often overcoming an individual's aversion to safety measures requires that someone address underlying issues, such as pride or ego. There is no place for false bravado in the workplace. In the end, using safety gear does not make you less of a person, but it can keep you a living and healthy one.

The best way to build a culture of safety is to start cultivating the mindset early and reinforce it often. Existing employees need to be retrained regularly. Orientation for new employees should include in-depth safety training before they begin any field work. It is crucial that new installers learn every task within the context of the proper safety mechanisms. When the expectation that working safely is enforced right at the beginning of employment, and is inherent to the job description, everyone sets off on the right foot. Similarly, existing employees being promoted to higher levels of responsibility should attend refresher safety courses or receive additional or complimentary safety training, on par with their new responsibilities.

Roles and responsibilities. Making sure that safety is a core company value and that a proper safety program is developed is an equal burden on all companies, regardless of size. Depending on their size, however, companies allocate resources differently when creating, managing and implementing a safety program.

It is clearly a bigger challenge for smaller companies to allocate the resources needed to fully develop a safety program. New companies or small businesses may decide to outsource these tasks to an independent safety consultant or safety provider. Otherwise, managers who may already have multiple hats to wear have to add safety program management to their other roles.

Midsize and larger companies should be able to commit resources to building a dedicated safety team. This team might be headed by a safety director and include safety engineers, as well as qualified specialists to handle documentation, training, record keeping and auditing functions.

A company with a large workforce spread out across numerous jobsites needs robust management systems in place. A great deal of information needs to be managed and communicated to track training requirements, employee turnover, equipment allocations, audit results, disciplinary actions and so forth.

Training and certification. A well-trained workforce is a safer workforce. Safety training opportunities are diverse and readily available. For example, OSHA 10- or 30-hour classes are offered online, taught in a classroom setting in major markets and can even be arranged on-site to suit your schedule. Specialized training is available on a variety of safety topics, ranging from forklift operation to fall protection to first aid. While the scope and quality of the content varies from one class to another, formal trainings are an excellent tool for building a more knowledgeable workforce.

The Interstate Renewable Energy Council (IREC) was founded nearly three decades ago with CONTINUED ON PAGE 120

the mission of responsibly ensuring broader adoption of renewable energies. In the mid-1990s, IREC created the Institute for Sustainable Power Quality (ISPQ) to develop assessment standards for individuals and institutions teaching renewable energy and energy efficiency courses. One of the goals of the ISPQ assessment framework is to determine if training programs include procedures that ensure safe practices. Therefore, one way to evaluate a solar installation training opportunity is to see if the program is ISPQ accredited or if the instructor is ISPQ certified. When either condition is met, students are likely to receive quality education that is anchored in safety and has met established standards for course content and presentation.

"Worker safety starts with good and continual training," explains Jane Weissman, executive director of IREC. "Teaching to the right skill sets promotes good workmanship and customer acceptance. Additionally, teaching jobsite safety and safe working practices protects both the worker and the consumer. That is why the ISPQ credentialing process developed by IREC considers the commitment to safety and safe practices a core requirement for all training programs and instructors."

Since the best way for most workers to learn is by doing, there are few substitutes for hands-on training led by a qualified individual in a controlled environment. This type of safety training lets workers become familiar with the equipment and procedures, while allowing them to ask questions and receive direct instruction from an expert. Complementing regularly scheduled (monthly or quarterly) in-depth trainings with more frequent, shorter training sessions is a good way to maintain an active focus on jobsite safety. Weekly tailgate meetings not only serve as a refresher regarding safety policies and procedures, but also facilitate a steady two-way exchange of ideas between management and workers.

Alternative training methods, such as online classes, may be adequate for certain topics. Online courses can be quite comprehensive. However, they usually lack the back-and-forth exchange that a live training session provides, not to mention the hands-on component that is critical to teaching certain processes.

Along with training, certification plays an important role in a successful safety program. It is not uncommon for a specific certification to be required for an individual to legally perform certain tasks or types of work, such as forklift or heavy equipment operation. Because certification requirements vary by jurisdiction, you need to pay careful attention to the details of local regulations and state laws.

The North American Board of Certified Energy Practitioners (NABCEP) was established to develop quality credentialing and certification programs for installers in the field of renewable energy. A primary goal of NABCEP's voluntary certification programs is to promote worker safety.

According to Ezra Auerbach, executive director of NABCEP: "Worker safety is one of the core CONTINUED ON PAGE 122

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The Strength to Deliver

foundations of a meaningful certification program. There are two significant ways that worker safety is supported through certification: during the examination process the candidate's knowledge and awareness of all elements of safety related to the specific job is tested; and throughout the recertification cycle safety is a part of the emphasis in continuing education requirements."

To specifically address safety issues, NABCEP is working proactively on a number of fronts. "NABCEP is engaged with OSHA and other stakeholders in an effort to define an appropriate suite of safety trainings for solar workers," Auerbach says. "We also use our newsletter as a vehicle to convey important messages, like changes to OSHA regulations. We build job safety content into every job task analysis and examination program that we offer. With the PV Technical Sales certificate program, which was developed and added in 2010, we even established the precedent of making the OSHA 10-hour safety training a prerequisite for taking our exam."

> "We will continue to seek ways to elevate jobsite safety standards and worker awareness, because we think it is a critical component of what we can offer our certificants, their customers and the industry in general."
> —Ezra Auerbach, NABCEP

Certification programs from UL University and the National Roofing Contractor Association (NRCA) offer parallel PV certification paths for tradespeople from the electrical and roofing industries. To receive the UL PV System Installer Certification, individuals must have completed the OSHA 30-hour safety training for construction. At present, this prerequisite is the highest safety standard being applied to any North American PV installer certification. To evaluate and certify solar roofing professionals, NRCA and the Center for Environmental Innovation in Roofing founded Roof Integrated Solar Energy (RISE), which developed the Certified Solar Roofing Professional recognition.

Safety policies and procedures. Documented policies and procedures that detail how to perform work safely are essential. Having workers rely on hearsay, memory or tribal knowledge is not a long-term solution for keeping them healthy and safe. Instead, document what is expected of all employees and describe how to perform specific tasks safely. This documentation not only

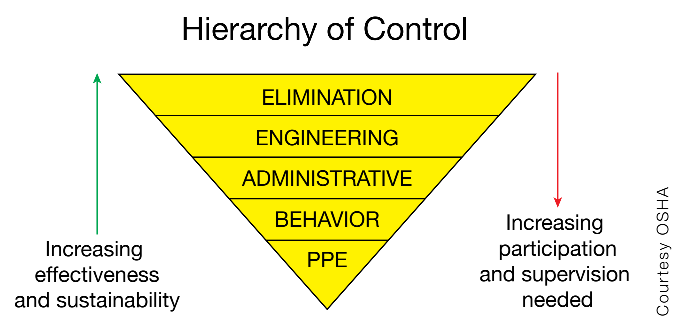

Figure 2 When a hazard is identified, OSHA requires that the highest possible level of control is applied, commensurate with the risk level. Lower value controls may be used in the interim until long-term controls are implemented.

becomes an instructional tool that workers can easily refer to, but it also maintains OSHA compliance.

Establishing operating procedures and communicating them to workers is among the most important employer responsibilities under the Occupational Safety and Health Act of 1970. Policies should be written so that employees can implement them in their daily work. Policies should also adhere to what OSHA refers to as the *hierarchy of control,* which is shown in Figure 2.

As defined by OSHA, a *hazard* is something that can cause harm if not controlled. The principle behind the hierarchy of control is that the highest level of protection must be used to control any hazard, unless that level of control can be proven infeasible. Added expense, difficulty or implementation time is generally not an acceptable argument for implementing an insufficient level of control. Following this principle, an electrician should never be issued PPE and expected to work on live circuits as long as it is possible to interrupt the source of power, which effectively eliminates the hazard.

To create effective policies, you must analyze every step of the PV installation process. Establishing blanket policies is tricky because of the wide variety of tasks performed and the uniqueness of every installation. Having an intact feedback loop between installers in the field and safety program leaders is critical. Real-time support from jobsite supervisors is often necessary in order to quickly address situations encountered.

If safety directors are not intimately familiar with the work being performed, they should spend time working side-by-side with the crews. Crafting good policies and adopting effective solutions requires a practical understanding of specific job tasks and working environments. Workers can get frustrated if safety policies are not realistic, which frequently is the case when proper consideration is not given to details. An unfortunate consequence of this frustration is that policies that have lost their credibility are often simply disregarded.

Safety gear and hardware. Selecting safety gear is similar to choosing any other product. You need to CONTINUED ON PAGE 124


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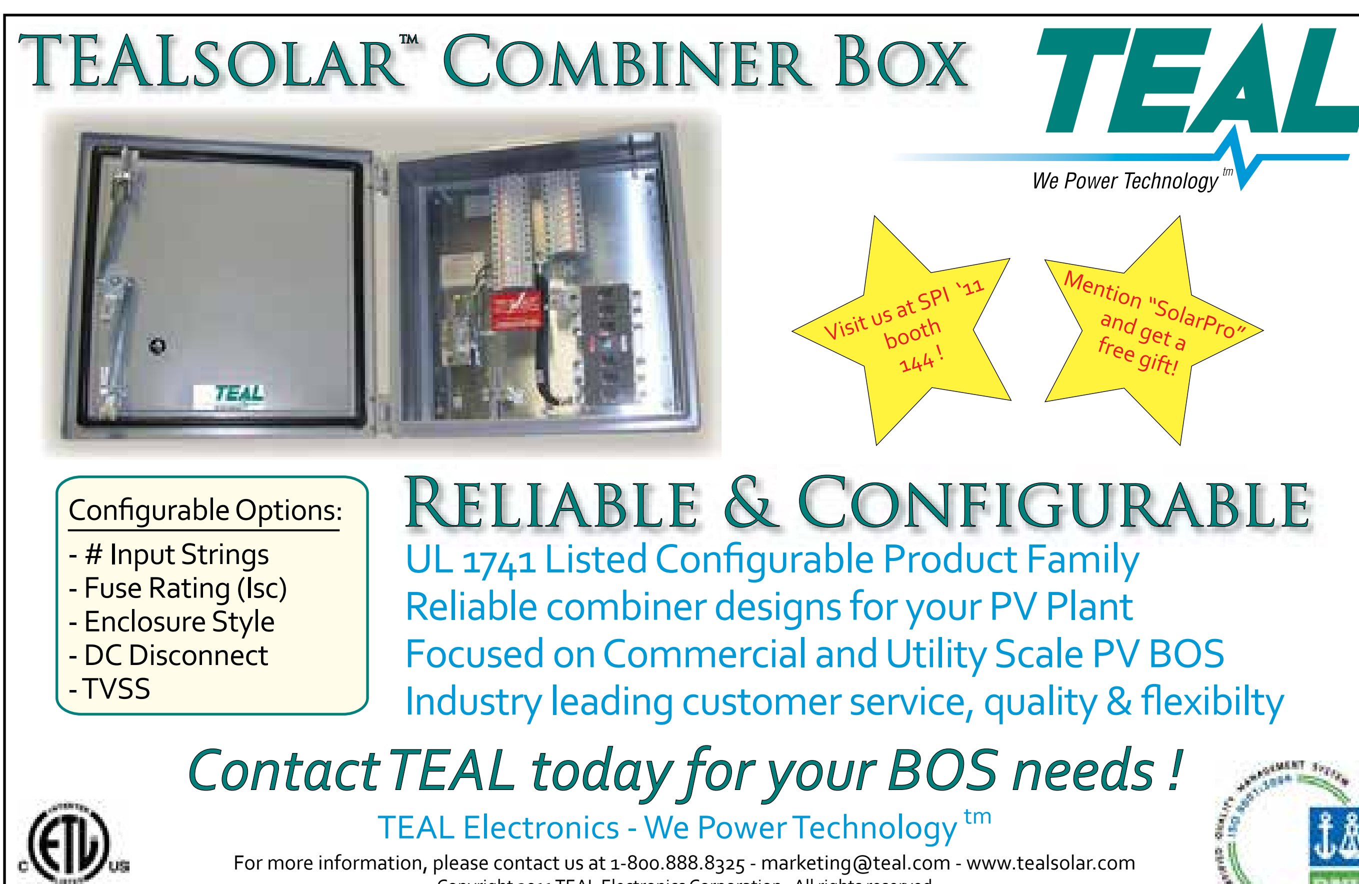
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understand how the product is intended to be used and determine whether that meets your needs. While catalogues and websites are good places to start your research, you should also review technical specifications and instruction manuals before making major purchases. If it is unclear whether a product meets your specific requirements, contact a technical sales or applications support specialist, either through your distributor or the manufacturer.

Safety equipment manufacturers are beginning to take notice of the solar industry. While our needs are similar to and overlap with the wind or general construction industries, they are also slightly different. For example, the standard metal cable used in some retractable lifelines can damage PV module frames and may increase shock hazard. One alternative is to use a retractable lifeline with a nonconductive, synthetic webbing. However, these synthetic materials might not be durable enough for use on abrasive asphalt-shingle roofs or where cables are constantly being pulled over aluminum edges of racking and module frames.

One company dealt with this issue by reaching out to various manufacturers of fall protection equipment. Guardian Fall Protection responded by developing a custom retractable lifeline with a protective coating over a metal cable that provides a nonconductive protective layer between the cable and the modules.

As the solar industry continues to grow, we will undoubtedly see more safety products tailored specifically for our needs. For example, the lifting group at BOECKER USA, which has a nearly 50-year history with crane and lift technology, has supplemented its construction lifts with a product specifically designed to transport PV modules onto multistory residential and light commercial rooftops. This is the TopLift ECO, which is similar to other "laddervator" products commonly used by roofers, but has a specific attachment for PV modules. More recently, the company added the BOECKER SMV 150, a universal staging platform for modules that hooks to horizontal mounting rails and can be easily slid laterally on casters.

As with other equipment purchases, you need to weigh quality versus cost when choosing personal safety gear. You should select PPE that is comfortable to wear, and listen to employee feedback. One benefit of investing in comfortable, high-quality PPE is that workers are more likely to accept and use this gear over something cheaper and less comfortable. It is important to instill and cultivate accountability with regard to safety gear. To reduce the likelihood of loss CONTINUED ON PAGE 126

or damage, consider assigning PPE directly to individual workers, as ownership implies accountability.

OSHA requires that a *competent person* inspect all safety gear before each use. Also, the worker needs to record the date that a personal fall protection system is put into service. OSHA mandates that a *qualified person* inspect these systems biannually. Failure to record service and inspection dates can lead to an OSHA citation. (See QA, pp. 16–22, for OSHA's definitions of *competent person* and *qualified person.*)

In the end, proper selection, inspection, maintenance, installation and use of safety hardware is more critical than the brand name. While it is a significant investment to provide every installer with a personal fall protection system, full PPE and electrical safety gear, this needs to be accepted as a fundamental cost of doing business, along with buying or leasing guardrail systems, scaffolds or material lifting devices.

Documentation and record keeping. Your safety program's details and actionable policies need to be spelled out on paper and reviewed by all employees. This is the best way to communicate what is expected. However, this is only the beginning of the documentation and record keeping required.

Each jobsite requires its own project safety plan prepared by a competent person. The project safety plan must explain in detail what hazards are present at the site in relation to the work being performed and what measures are being taken to mitigate these hazards. For auditing purposes, this project safety plan should include sign-in sheets to document that all workers coming to the site have reviewed the specifics of the safety plan. Workers must sign off on the plan prior to commencing their tasks.

It is not sufficient to use a blanket safety plan to cover multiple similar locations over time, unless each location is identical and the scope of work is also identical. Each job requires an individual safety plan. While installing rooftop PV is similar from one jobsite to the next, the details of the safety plan will differ according to the location of hazards, roof access and scope of the work performed.

Similarly, a written record is required for every training or safety meeting, and attendance must be documented by means of a sign-in sheet. Safety equipment inspections need to be documented and a record of these CONTINUED ON PAGE 128

SEIA's Installer Safety Task Force

The Solar Energy Industries Association (SEIA) has created an Installer safety task force within its Environmental Health and Safety group. SEIA recognizes that employee health and safety is an important component of building a sustainable industry.

The mission of the task force is to raise awareness about installer health and safety, advocate for safe working practices, assist companies by providing guidance and resources and otherwise improve the overall state of employee safety across the industry. At the PV America conference held in April 2011, in Philadelphia, Pennsylvania, the installer safety task force hosted a jobsite safety panel discussion. The panel, which was well received, included the safety program director for a national PV systems provider, an OSHA compliance specialist, a representative from the insurance industry and an expert on fall protection.

The task force also has plans to host recurring webinars covering specific safety topics, possibly with IREC as a partner. In addition, initial planning stages are under way for a PV installation safety seminar to be held in early 2012. Visit SEIA's website (see Resources) for up-to-date information.

State and regional SEIA chapters have also been hard at work on the installer safety issue. For example, Oregon's state SEIA chapter (OSEIA) created the *Solar Construction Safety Manual,* which provides excellent information about how to work safely while installing PV and solar thermal systems. This document is available to the general public at the OSEIA website. The California SEIA chapter (CalSEIA) also has a safety manual that is available to members at its website. (See Resources for these websites.) ●

Courtesy Cupertino Electric

Practical understanding If safety directors are not intimately familiar with the work being performed, they should spend time working side-by-side with the crews. Creating good policies requires a practical understanding of the job.

inspections must be maintained. If safety certifications are needed to perform certain tasks, the certifications need to be recorded. Copies of valid employee certifications should be kept on file and expiration dates should be tracked. Written policies regarding accident reporting are also required. Finally, documents need to be maintained in locations where they can be reliably accessed as needed by office or field personnel.

Failure to keep records can cause major problems. In the event of a serious accident, investigators look to these documents for proof that workers were properly trained and equipped to perform their duties. In the eyes of the investigator, employee training or equipment maintenance might just as well never have happened if there is no documentation.

Oversight and enforcement. Some level of management oversight is required to ensure that documented safety policies are consistently and properly implemented in the field. Generally this takes the form of a site safety audit that is performed by a safety program manager or supervisor who is fully versed in the company safety policies. Closing the loop in this manner guarantees a more consistent outcome and fosters a useful dialogue. Site safety audits are an excellent opportunity for safety team members to clarify what is expected of workers in the field, while getting feedback from the crew about the effects of different policies.

To ensure consistency in reporting, develop a standard site safety audit form. This serves to simplify record keeping and to generate useful data. Tracking and comparing the results of these questionnaires over time helps highlight areas for improvement. In some cases, the policies or procedures themselves may need to be reexamined. In other cases, the training content may need to be revised. These results can also be useful in determining the ideal frequency of audits.

Performing regular safety audits invariably leads to questions about enforcement. How are you going to handle substandard safety performance? These are decisions that every company needs to make on its own. However, retraining, write-ups and suspensions are the norm, followed by termination for habitual violators.

Having clearly documented safety polices pays dividends when it comes to oversight and enforcement. Provide objective guidelines for workers to follow and minimize ambiguity. If employees understand what is expected of them and the standard they are being measured against, then safety audits and any consequences that follow come as no surprise. CONTINUED ON PAGE 130

A culture of safety
At the end of the day, safety needs to be a priority on par with competing interests like installation speed and cost. Implementing a successful safety program requires buy-in from everyone—from the executive team down to the crew on the roof.

Shawn Schreiner

Feedback and constant improvement. Like any other aspect of a successful business, safety programs should be regularly reviewed and constantly improved. Data from site safety audits are useful in this effort, as is worker feedback. A partnership founded on mutual respect can form through ongoing and open communication between workers and the safety team.

Lessons learned from accidents are invaluable for improving safety program policies and procedures. You also want to monitor new developments in safety hardware and the latest industry best practices. Changes in OSHA standards or local regulations may trigger changes to your safety program.

There are behavioral and administrative challenges associated with making major changes to your safety program. One challenge is that workers need to be retrained to the new policies and may need to unlearn ingrained behaviors. In terms of program administration, it can also be a challenge to remove all traces of an obsolete policy from program documentation, such as training manuals or audit forms. In order to accomplish these goals, everyone needs to work together. The safety team needs to understand that workers may struggle with new regulations until they have had some time to adjust to them. During that adjustment period, the safety team needs to answer questions and provide guidance on how to implement the policies.

In general, workers want to do the right thing and implement policies as directed, but they can be stumped when policies do not exactly fit the situation they are faced with. This is why they need to have ready access to expert technical safety support. Ultimately, expert guidance helps workers learn how to make better decisions on the fly and improves their problem solving skills going forward.

Getting involved. Working safely is everyone's responsibility. If your state SEIA chapter does not have its own construction safety manual, you can help it publish one. If a local solar workforce training program is insufficient, you can help improve the curriculum.

If you feel that you are lacking the right skills, find and attend classes that will bring you up to speed. Get your OSHA 30-hour training certificate. Take fall protection courses to become a competent person or better yet a qualified person. Read up on OSHA regulations. Research best safety practices for the construction industry. Speak to your superiors about how the level of safety at your workplace can be improved. Become an advocate for safe working practices at your company and lead by example.

CONTACT

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Resources

BOECKER / boeckeramericas.com
Christine Covington / SEIA Installer Safety Task Force / ccovington@seia.org
California Solar Energy Industries Association (CalSEIA) / calseia.org
Garlock Safety Systems / railguard.net
Guardian Fall Protection / guardianfall.com
Interstate Renewable Energy Council (IREC) / irecusa.org
Roof Integrated Solar Energy (RISE) / riseprofessional.org
National Roofing Contractor Association (NRCA) / nrca.net
North American Board of Certified Energy Practitioners (NABCEP) / nabcep.org
Occupational Safety and Health Administration (OSHA) / osha.gov
Oregon Solar Energy Industries Association (OSEIA) / oregonseia.org
Solar Energy Industry Association (SEIA) / seia.org
UL University / uluniversity.us


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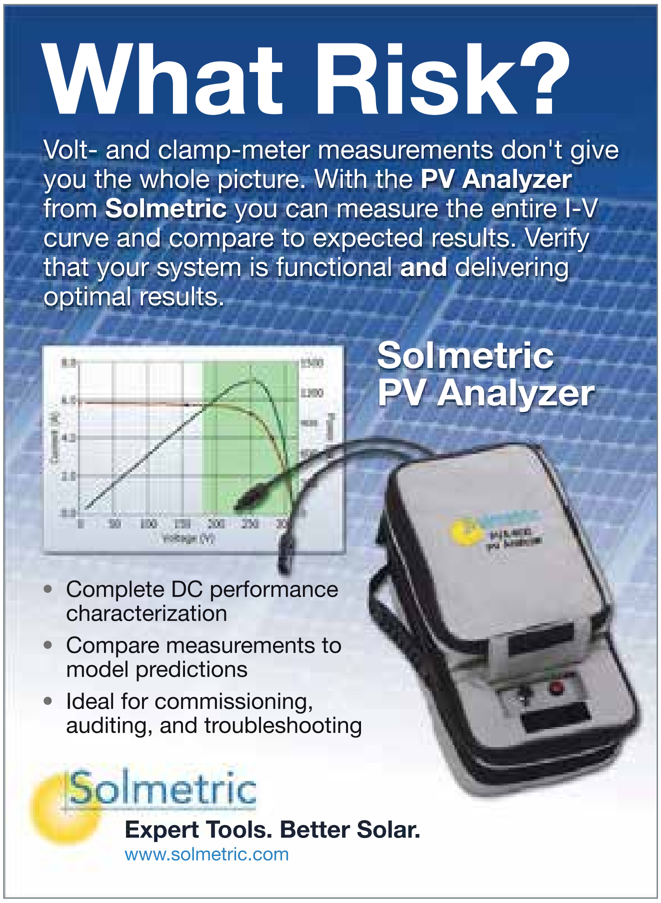
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Interview

An Experienced Perspective

Mike Holt, Mike Holt Enterprises

NEC Expert and Electrical Trainer

Mike Holt worked his way up through the electrical trade from apprentice to master electrician and electrical contractor. In 1973, he began teaching electrical classes, and by 1980 he had stopped contracting and was focused solely on training. Now, Holt is nationally recognized as an expert on the *NEC* and is one of the most knowledgeable electrical instructors in the US. His series of books and videos are used across the country by numerous training centers, electricians and engineers. His books include *Understanding the* National Electrical Code, *Grounding vs. Bonding* and, his newest in the series, *Understanding* NEC *Requirements for Solar Photovoltaic Systems.* After dropping out of high school, Holt later received his MBA from the University of Miami. Ryan Mayfield, *SolarPro* magazine technical editor, recently spoke with Holt.


Courtesy Mike Holt Enterprises

Mike Holt, Founder, Mike Holt Enterprises As an unrelenting student of the *NEC* himself, Holt encourages everyone involved in the electrical industry to continuously work on their own *Code* knowledge.

RM: How did you get involved in training and writing?

MH: When I took my very first test as a journeyman electrician, there were no books or classes to help prepare for the exam. I was also told that there was essentially a quota system in place where only a certain number of people passed. I was intimidated and I didn't know what to study, so I pieced together the few documents I could to study from.

I took my test, and I scored a 96. I left there stunned. If this thing was fixed, then I wouldn't have passed. That means that the test was not fixed and all those rumors were not true. If you study and prepare, you will pass.

Someone then suggested I teach a class for other guys who are intimidated. I approached the principal of a high school that offered evening vocational classes and suggested it. He said they had never done such a thing, but they would advertise the class and see what happened. The first night, I had 80 people in that class. About 3 months later, I decided to go into the business of teaching. The first class I ever taught on my own, I had 50 people enrolled. That's how it started back in 1973.

RM: The majority of your books are based on the *NEC,* requiring updates every 3 years. In addition, you produce business management, electrical estimating, electrical theory and exam preparation materials. How are you able to produce such a wide variety of books and videos? What does your support staff look like?

MH: Number one, it's overwhelming. For each book and the associated material, it is a full year's commitment. Obviously I can't do all that work by myself.

People on my staff and individuals from various parts of the electrical industry assist me. Mike Culbreath, who does our graphics, has been with me for 25 years. I have experts in the field—like you, Ryan, and Bill Brooks—to help with the solar book. I have great *Code* guys like Ryan Jackson and Steve Arne to help with my other publications.

So, I have technical people who can look at our work and say, "Well, wait a minute, now. Is this correct? Did you interpret this change correctly?" An important piece for me is having great technical people who are committed to making a safe installation. They're there because they've all been successful and feel a desire, like I do, to give back to the industry and maybe help the next generation to be better than us.

RM: How many books and videos do you produce on a regular basis? Does Mike Holt Enterprises publish all the books you write?

MH: I think at the last count there are probably about CONTINUED ON PAGE 134

26 different DVDs. There are probably 18 to 20 different books. We publish everything, from the graphics to the books and DVDs. The only thing we don't do is physically print the books and physically burn DVDs. Other than that, we do everything in-house.

RM: You host seminars on various electrical topics as well. Are all of the classes held in Florida, or do you travel?

MH: I do only two classes a year in Florida, for Florida Continuing Education. Other than that, I speak at various conferences like Solar Power International and Electric West. Mike Holt Enterprises is not in the business of doing seminars. But as I travel around the country for different organizations, it allows me to stay connected with my customers to understand their needs.

RM: The forum on your website is a great resource that individuals in the electrical industry can access for free. It looks like the PV section of the forum is very active, too. Is this an area you find your staff dedicating a lot of time to? What do you see as the biggest benefit to maintaining such a large forum?

MH: The forum wasn't anything we planned. It took off on its own. I never go on the forum and my staff pretty much never do either. We made it independent. We do have moderators; these are people who are willing to give their own time for topics like solar power or surge protection or lightning protection or grounding or whatever the topic might be, to help the industry as a whole. The moderators are there to remove advertisements, offensive posts and posts from do-it-yourselfers or homeowners. Every section of the forum has multiple volunteer moderators. For all practical purposes, very little energy from Mike Holt Enterprises as a company is spent on the forum. I do have two webmasters, multiple servers and other associated necessary equipment.

It is satisfying to see this forum take off like it did. One day, I'm going to be gone, and I'd like everything I've gained and the knowledge I have to be out there. The forum allows other people to make it available for future generations.

Courtesy Mike Holt Enterprises

National Barefoot Water Ski Champion Holt finds that the hard work, planning, risk awareness, commitment and association with like-minded people from barefooting translates to useful lessons in business.

RM: Your involvement in the PV industry is relatively new. What prompted you to venture into a new field?

MH: I didn't want to get into PV. I was done. I'd written enough books; I'd produced enough DVDs. My customers kept asking for a book on PV systems, though, so they compelled me. As a business, you have to take care of your customers.

RM: Once you decided to jump into this area, you needed to gain PV-specific knowledge quickly. You even became a NABCEP Certified Solar PV Installer. How did you receive training on PV-specific issues?

MH: Once I realized that solar was not going to go away, I went to my very first seminar with SMA America. Greg Smith was the first instructor I ever saw on solar. He did a great job and he really helped me understand the basics. I also went to the UL University program. I had a private class with Jim Dunlop so I could get sufficient credits. I supervised, inspected and reviewed the jobs for electrical contractors local to me. This really let me get into the practical part.

You can get all the book knowledge and learn the codes, but until you are actually physically in front of a piece of equipment, designing a system, installing and commissioning it, you don't really get it. It takes that practical experience in addition to book knowledge to get the "Aha! Now I see why that rule is that way. Now I see why they want you to do it this way."

RM: How have your PV book (*Understanding* NEC *Requirements for Solar Photovoltaic Systems*) and Solar Boot Camp been received in the short amount of time they have been available?

MH: We've gotten calls from people who are saying, "Wow, finally."

I think my book helps a lot of the solar program designers to rethink their curricula. They realize, "You know what, we need to cover *Code*." This means not using a general book that covers everything, then sprinkles in a little about *NEC* rules. The problem with most other solar books that cover *Code* is that they're not current to the most recent *Code* version. Now the schools can have books on the fundamentals of solar design and mechanical installation, things we don't cover, and also have our complete and current review of *Code* as it pertains to solar.

RM: One of the almost universal comments I hear about your books is how easy-to-understand the graphics are. How have you perfected them over the years?

MH: As an electrician studying on my own, I would CONTINUED ON PAGE 136


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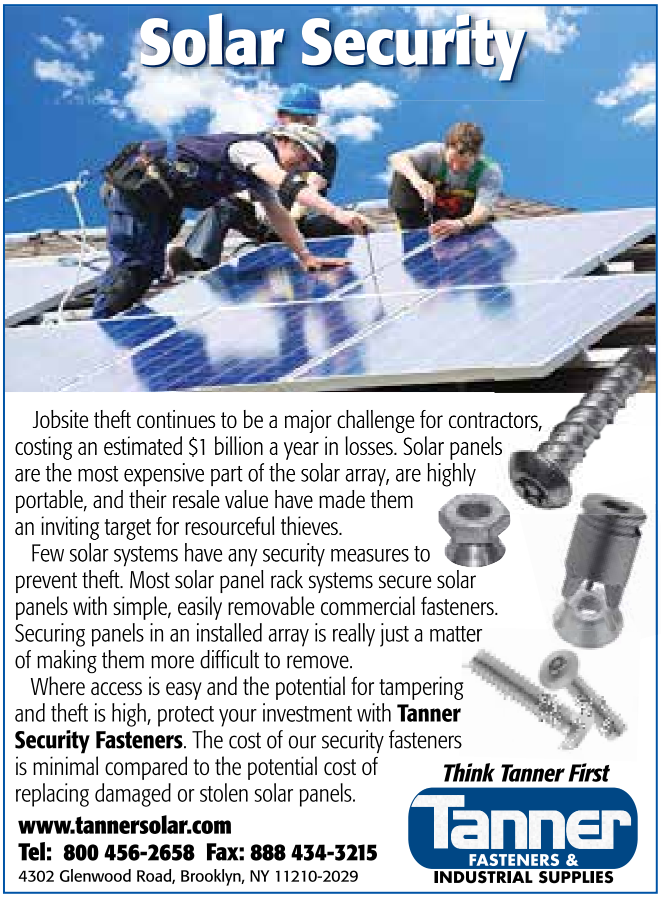
Solar Security
Jobsite theft continues to be a major challenge for contractors, costing an estimated $1 billion a year in losses. Solar panels are the most expensive part of the solar array, are highly portable, and their resale value have made them an inviting target for resourceful thieves.
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buy these electrical books and I couldn't understand them. They were just so engineered and technical. For the graphics, they would use single-line diagrams for everything, and I couldn't understand what was a box, what was a wire, what was a connector and what was a cable. Often the graphics were not to scale and they were always in black and white. I would have to sit there—and I remember this clearly—just sit there for hours reading over and over, looking at a graphic and trying to figure out what was what.

So I decided that for my graphics, everything was going to be to scale and in full color. By using graphics instead of photos, we can control exactly what we are showing. The text reflects the graphics. I spend a huge amount of time looking at every word, every sentence and every paragraph to decide what I can say with the least amount of words to communicate what the rule is saying. So we want to have simple words, simple text and lots and lots of graphics.

RM: Since you are heavily involved in the training aspect of *NEC,* how active are you with *Code*-making panels?

MH: I submit proposals, and then I submit comments to try to facilitate the clarification of the proposal or the rule to get it simpler.

RM: I know the electrical industry has changed tremendously since you started in the early '70s. You have one of the best reputations in the electrical industry. What have you done to stay on top of the changes and deliver products that keep your customers coming back?

MH: My customers tell me what they need, and it's my job to give them the products that meet their needs. Like you said, the industry has changed. What I did in 1973 is not what I did in 1980. What I did in 1990 is different from what I did in 1980 or 2000—and what I'm doing in 2011. The market and the customers are changing, and so is our job. We always do surveys to make sure we are delivering the right products.

RM: I think most people are surprised when they find out that the man behind Mike Holt Enterprises is a six-time National Barefoot Water Ski Champion.

MH: I've been really blessed with good genes. I'm skiing better today—and I'm almost 60—than I did 10, 15, 25 years ago. Barefooting allows me to get away from all electrical people and all electrical concepts. It's a whole different world, a different tribe that I associate with. When I leave that tribe and I come back to my electrical world, I'm rejuvenated and I'm ready to go—I'm excited.

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Solar Living Institute
Oct 10 – Oct 14
Nov 14 – Nov 18
Ukiah
solarliving.org

Solar Technology
West Contra Costa Adult Education
Oct 15 – Nov 5
Richmond
wccae.info

XW & Conext Training
Schneider Electric
Oct 19 – Oct 21
Livermore
schneider-electric.com

Post or view professional trainings online at: solarprofessional.com/training

Florida

Installing PV Systems
Florida Solar Energy Center
Oct 3 – Oct 7
Cocoa
fsec.ucf.edu

PV Design & Installation
US Solar Institute
Oct 3 – Oct 7
Oct 31 – Nov 4
Nov 28 – Dec 2
Fort Lauderdale
ussolarinstitute.com

PV Installer Training
ONTILITY – Miami-Dade College
Oct 10 – Oct 14
Miami
ontility.com

Advanced PV Installation
US Solar Institute
Oct 10 – Oct 14
Fort Lauderdale
ussolarinstitute.com

Indiana

Basic PV
Midwest Renewable Energy Association
Oct 8
Bloomington
midwestrenew.org

Iowa

PV 101
Iowa Renewable Energy Association
Oct 1
Nov 17
Hiawatha
irenew.org

Maryland

Solar Thermal Installer Certification Prep
IEC Chesapeake
Oct 10 – Oct 14
Jessup
iec-chesapeake.com

Massachusetts

Electrician's Introduction to Solar
ONTILITY
Oct 7 – Oct 8
Boston
ontility.com

New Jersey

PV Boot Camp
Boots on the Roof
Oct 31 – Nov 5
Newark
bootsontheroof.com

New York

Advanced Off-Grid PV Design
Ulster BOCES
Nov 1
Port Ewen
ulsterboces.org

Solar Hot Water Installation
Ulster BOCES
Oct 3 – Oct 14
Oct 3 – Nov 7
Port Ewen
ulsterboces.org

Basic PV Design & Installation
Electrical Training Center
Oct 3 – Nov 12
Copiague
electricaltrainingcenterli.com

Advanced Solar Hot Water Installation & Design
SUNY Ulster
Oct 14 – Oct 15
Kingston
sunyulster.edu

PV Technical Sales & Marketing
Ulster BOCES
Oct 24 – Oct 28
Port Ewen
ulsterboces.org

Solar Hot Water Installation & Design
SUNY Ulster
Nov 4 – Nov 6
Kingston
sunyulster.edu

PV Installer's Course
Ulster BOCES
Nov 8 – Dec 15
Port Ewen
ulsterboces.org

NABCEP PV Entry Level Exam
SUNY Ulster
Nov 18
Kingston
sunyulster.edu

North Carolina

PV Installation
UL University
Oct 3 – Oct 7
Nov 7 – Nov 11
Research Triangle Park
www.uluniversity.us

PV Installation Certification Exam
UL University
Oct 7
Nov 11
Research Triangle Park
www.uluniversity.us

Pennsylvania

PV Design & Installation
Electric Education Center
Oct 3 – Oct 7
Bensalem
electriceducationcenter.com

Texas

PV Installer Training
ONTILITY
Oct 3 – Oct 7
San Antonio
ontility.com

Electrician's Introduction to Solar
ONTILITY
Oct 7 – Oct 8
San Antonio
ontility.com

Advanced PV System Design
ImagineSolar
Nov 29 – Nov 30
Austin
imaginesolar.com

Utility-Scale PV System Design & Installation
ImagineSolar
Nov 7 – Dec 14
Austin
imaginesolar.com

Project Field Experience
ImagineSolar
Nov 8 – Dec 9
Austin
imaginesolar.com

Advanced PV System Installation
ImagineSolar
Nov 29 – Dec 13
Austin
imaginesolar.com

Utah

***NEC* 2011 for PV**
Salt Lake Community College
Oct 8
Salt Lake City
slcccontinuinged.com

Washington

PV Design & Installation
Solar Energy International
Oct 10 – Oct 15
Guemes Island
solarenergy.org

Wisconsin

PV Site Assessor Training
Midwest Renewable Energy Association
Oct 1
Milwaukee
midwestrenew.org

Solar Domestic Hot Water Systems
Midwest Renewable Energy Association
Oct 1
Pewaukee
midwestrenew.org

Intermediate PV
Midwest Renewable Energy Association
Oct 3 – Oct 4
Milwaukee
midwestrenew.org

Battery-Based PV Systems
Midwest Renewable Energy Association
Oct 4
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Advanced PV System Design
Midwest Renewable Energy Association
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Code Primer for Officials & Installers
Midwest Renewable Energy Association
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Advancements In PV
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Solar Water Heating Installation Lab
Midwest Renewable Energy Association
Oct 11 – Oct 13
Custer
midwestrenew.org

Canada

XW & Conext Training
Schneider Electric
Nov 9 – Nov 11
Toronto
schneider-electric.com

Online

Allied American University
allied.edu

Allied Schools
training4green.com

ONtility
ontility.com

Solar Energy International
solarenergy.org

Solar Living Institute
solarliving.org

Solar Training School
solartrainingschool.com

Step Up Education
solarclassesonline.com

Sun Pirate
sunpirate.com

Projects

System Profiles

ALTERIS RENEWABLES

Ferrisburgh Solar Farm

Courtesy Neil Dixon, Yankee Imaging

Overview

DESIGNER: Adam J. Smith, director of electrical engineering, Alteris Renewables, alterisinc.com

LEAD INSTALLER: Ken Mayer, Alteris Renewables

DATE COMMISSIONED: November 30, 2010

INSTALLATION TIME FRAME: 50 days

LOCATION: Ferrisburgh, VT, 44.3°N

SOLAR RESOURCE: 4.24 kWh/m^2/day

HIGH/LOW DESIGN TEMPERATURES: per solarabcs.org/permitting/map: 88°F/-15°F

ARRAY CAPACITY: 1.047 MW

ANNUAL AC PRODUCTION: 1,239 MWh

The 1.047 MW Ferrisburgh Solar Farm (FSF) is currently the largest solar installation in the state of Vermont. Located along a highly trafficked road in close proximity to a local high school, it includes a significant educational component. The project also supports the local economy. Alteris Renewables and the entire FSF team were proud to make this project the first PV system commissioned under Vermont's Standard Offer Program, a rebate structure designed to encourage the development of renewable energy projects.

The state obligated the team to acquire a Certificate of Public Good (CPG) for this project. Obtaining a CPG necessitates following a rigorous permitting process—the same required of electric transmission facilities, electric generation facilities and certain gas pipelines. Because a project of this size had never been done in Vermont, the team had to show local residents and town and state officials that the project would not adversely impact the community. They had to address concerns raised by state agencies relating to module reflectivity, inverter noise levels and storm water impact, among others. The team also worked closely with the electric utility, Green Mountain Power, to address interconnection and protection issues relating to MW-size PV installations.

One of the realities of designing a ground-mounted PV system in Vermont is that the significant annual snowfall must be taken into account. This presented the design challenge of balancing the optimal array tilt angle for snow shedding while avoiding significant inter-row shading. In addition, ample

Courtesy Alteris Renewables (3)

clearance under the array was necessary to attempt to prevent accumulated snow from obscuring the array's lower edge. The final design specifies a 30° module tilt with 48 inches of clearance between the ground and the bottom of the array.

This system was instantly put to the test by a series of record snowfalls. The project was commissioned in late November 2010, at the beginning of one of the snowiest winters on record. Three months after commissioning, as the snow kept piling up, the owners had doubts as to whether the system would meet its energy production forecast. During many winter days, the modules were covered with deep snow or with snow and ice. However, as anticipated, they cleared off relatively quickly when the sun came out. Despite the record snowfall, the system is right on target for producing the projected annual energy generation.

> "During the month of October, we received double the normal rainfall. As the clay field on which the system was being installed became saturated, machines were no longer an option for rack and module assembly. The majority of the array construction had to be managed with ladders. In spite of this significant obstacle, the job was brought in on time and on budget."
> *—Jay Myrto, project manager, Alteris Renewables*

Equipment Specifications

MODULES: 3,806 Suntech STP275-24/Vd, 275 W STC, -0/+5 W, 7.84 Imp, 35.1 Vmp, 8.26 Isc, 44.7 Voc

INVERTERS: 3-phase, 277/480 Vac service, two Advanced Energy Industries Solaron 500 kW, ±600 Vdc maximum input, ±330 to ±550 Vdc MPPT range

ARRAY: 11 modules per source circuit (3,025 W, 7.84 Imp, ±386.1 Vmp, 8.26 Isc, ±491.7 Voc). Inverter One: 186 source circuits total, with 93 positive and 93 negative-to-ground (562,650 W, 729 Imp, ±386.1 Vmp, 768 Isc, ±491.7 Voc). Inverter Two: 160 source circuits, with 80 positive and 80 negative-to-ground (484,000 W, 627 Imp, ±386.1 Vmp, 661 Isc, ±491.7 Voc).

ARRAY INSTALLATION: Fixed-tilt ground mount, Schletter FS System rack, 180° azimuth, 30° tilt

ARRAY STRING COMBINERS: 22 Cooper Crouse-Hinds model CCBF16F15DS200, 15 A fuses

ARRAY RECOMBINERS: Two Controls Engineering and Services model 27600, 225 A fuses

SYSTEM MONITORING: Draker Laboratories Sentalis 1000 Base Station, SHARK Energy Meter, weather station including plane-of-array irradiance, cell temperature and ambient temperature

Advertiser *Index*

PROJECTS

HOLOCENE
National Naval Medical Center

Overview

DESIGNER: Ben Gravely, PhD, director of technology, Holocene, holocene-energy.com, solarhotwater-systems.com

LEAD INSTALLER: Terry Holthaus, project manager, Holocene

DATE COMMISSIONED: June 29, 2011

INSTALLATION TIME FRAME: 45 days

LOCATION: Bethesda, MD, 39°N

SOLAR RESOURCE: 3.9 kWh/m^2/day

ANNUAL HEATING DEGREE-DAYS: 4,101, base 65°F

RECORD LOW TEMPERATURE: -5°F

COLLECTOR ARRAY AREA: 2,000 sq. ft.

AVERAGE ANNUAL PRODUCTION: 480 MBtu (141 MWh)

Equipment Specifications

COLLECTORS: 50 Alternate Energy Technologies (AET) AE40, 40 sq. ft. each

HEAT EXCHANGER: Power Plus International, custom

PUMP: Goulds 5SV4

STORAGE: 2,500-gallon Holocene Technologies Fluid Handling System with embedded heat exchanger, pump and controls

CONTROLS: Goldline GL30 Delta-T controller, autofill system with ASCO solenoid valve

FREEZE CONTOL: Drainback configuration

COLLECTOR INSTALLATION: Low-slope roof, bituminous roofing material, custom collector array mounts, 180° azimuth, 35° tilt

SYSTEM MONITORING: Badger 228BR flow meter with 3060 transmitter on DHW exchanger

Courtesy Holocene (2)

In June, Holocene commissioned a 50-collector commercial solar water heating system at the new Warrior Transition Unit facility in Bethesda, Maryland. Part of the National Naval Medical Center, the Warrior Transition Unit supports wounded soldiers who require at least 6 months of rehabilitative care and complex medical management. The system was designed to provide more than 30% of this facility's annual hot water demand for kitchen use, showers and laundry services.

One of Holocene's principal challenges was coordinating the installation within a dynamic and fast-paced construction environment. Impressively, Holocene was the first contractor to successfully commission its system on the project. Comprehensive training of the Naval Facilities Engineering Command maintenance staff was a key component of system commissioning.

The collector array is configured in banks of five collectors in parallel, which are plumbed into the main collector supply and return piping. This approach minimizes system temperature differentials and increases overall system efficiency. Because the system relies on drainback for freeze protection, careful attention was given to the proper installation of the supply and return piping.

The 2,500-gallon Fluid Handling System (FHS), manufactured by Holocene Technologies (a subsidiary of Holocene, LLC), is located in the facility's basement. The component's hot water exchange and storage approach is based on a design developed in the 1970s by Ben Gravely, Holocene's director of technology. The FHS utilizes a nonpressurized, insulated steel tank and has no heat exchanger between the collectors and the tank.

> "The FHS contains specified pumps, heat exchangers, controls and monitoring components in one integrated package. Factory-built storage systems provide greater quality control and lower installation costs, and are very well suited for commercial water heating installations."
> *—Ben Gravely, PhD, Holocene*

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Kohl Christensen, Oahu, Hawaii
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