September/October 2018

Residential Solar-Plus-Storage Systems

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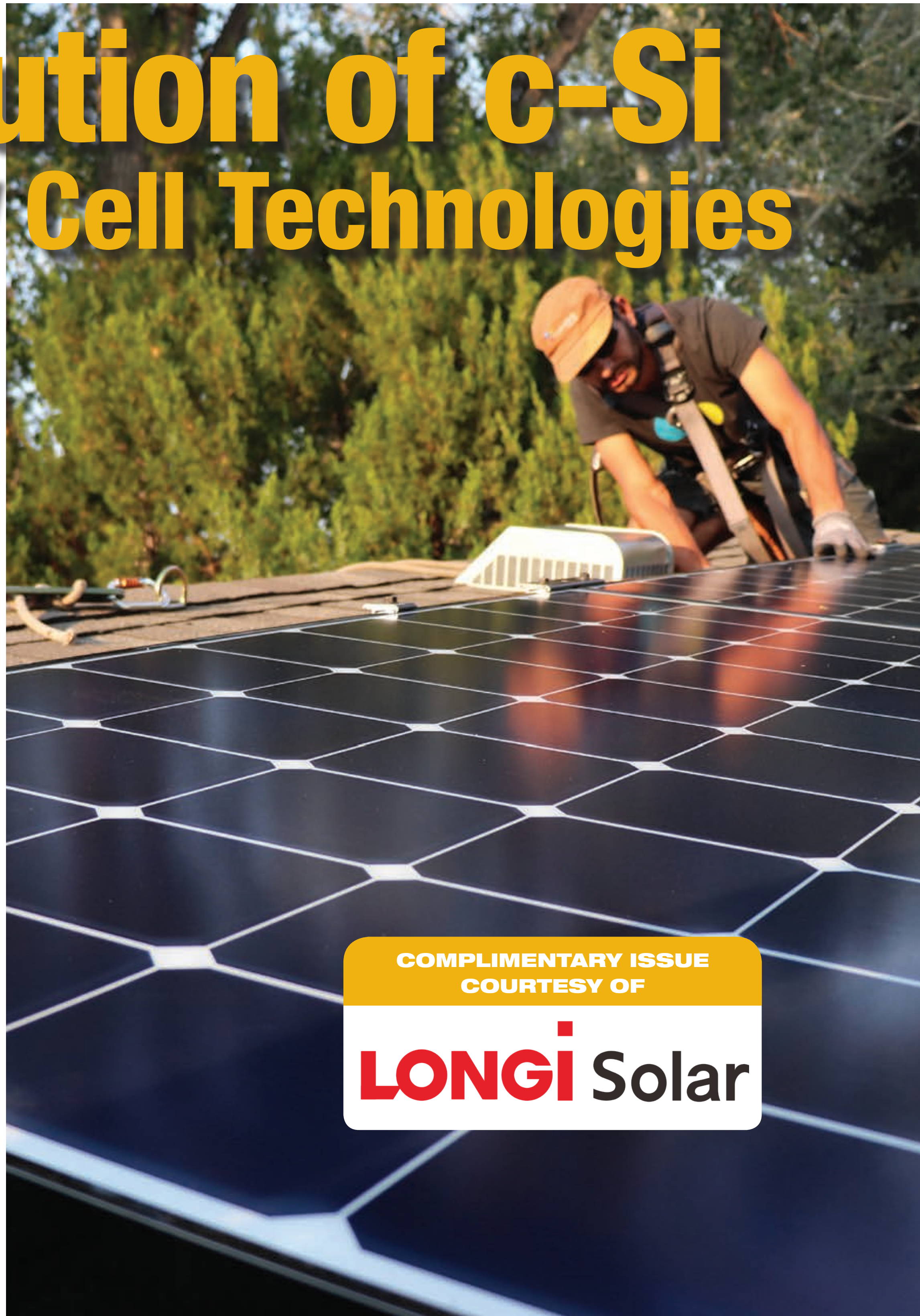


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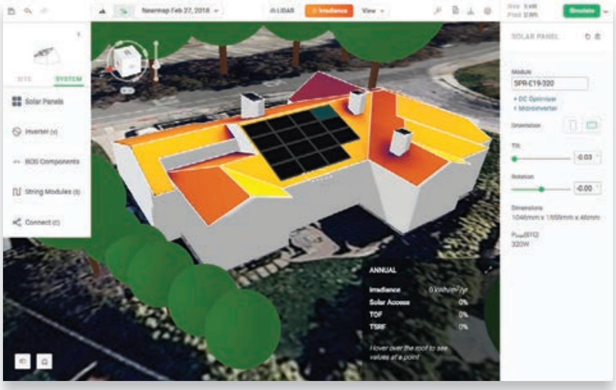

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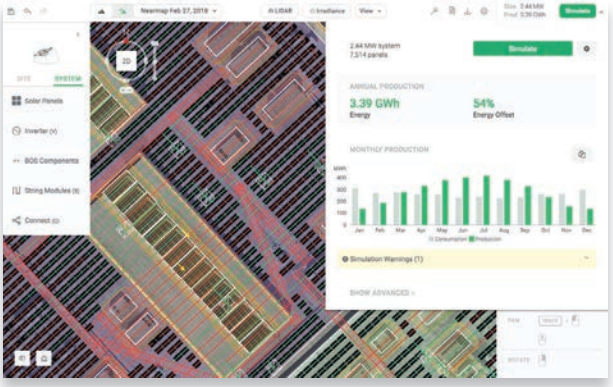

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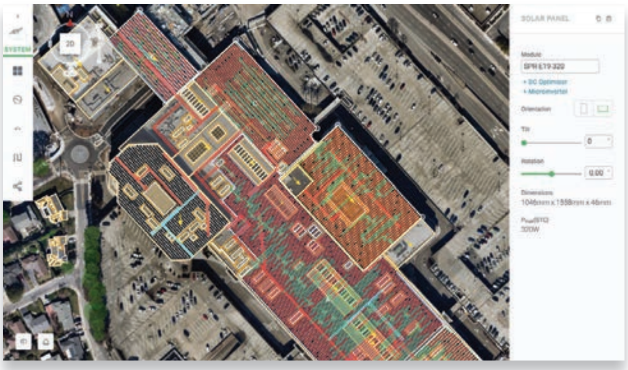

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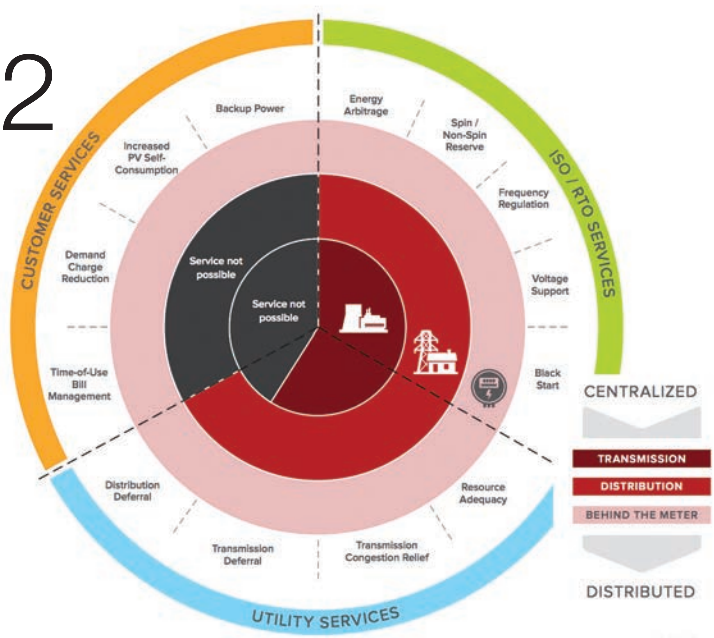


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**ON THE COVER** **Namasté Solar's Jason Ortiz wraps up the roof work on a 3.85 kW residential PV system in Fort Collins, Colorado. The system includes high-efficiency 350 W LG crystalline silicon modules, a SolarEdge inverter and module-level power optimizers, and an Ecolibrium Solar railless module-mounting system.**

Photo: Courtesy Namasté Solar


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## With the New ME-ARTR Advanced Router

The ME-ARTR Advanced Router from Sensata Technologies is designed to connect large, residential Magnum Energy solar + storage installations. The Advanced Router provides complete system-level connectivity and programming for up to 42kW harvest, as well as:

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# SolarEdge Introduces P850 Commercial Optimizer

**[Fremont, CA]** SolarEdge has introduced the P850 2:1 commercial power optimizer, which replaces its P800s power optimizer model. The P850 connects two modules in series and is designed for compatibility with two 60-cell, 72-cell and bifacial modules. It supports up to 850 W and is rated for 12.5 A at up to 120 Vdc. The P850 has a redesigned bracket to simplify clearance requirements. It is backward compatible with P800s power optimizers and can replace the P800s in all projects. The existing SolarEdge P800p power optimizer is typically used to connect two 96-cell high-current modules in parallel. Together, the P850 and P800p power optimizers address the growing deployment of higher-power and higher-current modules.

**SolarEdge / 510.498.3200 / solaredge.com/us**

## Planet Plan Sets Launches

**[Placentia, CA]** The recently launched Planet Plan Sets streamlines the process of obtaining third-party permitting plan sets for residential PV and energy storage systems. Its base product offering includes full, detailed plan sets with three-line diagrams; a site view showing equipment locations, conduit runs and fire setbacks; racking system specifications; weather sealing and foundation details; attachment spacing; wire and conduit sizing; interconnection specifications; grounding information; placard and signage details; and product specification sheets. Planet Plan Sets also offers structural engineering documents stamped by a licensed professional engineer with all calculations for a specific project, custom-engraved house placards designed to meet *NEC* requirements and solar interconnection application processing. Integrators submit all project information via the company's website and receive a completed permitting plan set in 2–3 business days. Pricing for the base plan set product is $249 for a grid-direct PV system of up to 10 kW and $349 for a system that incorporates energy storage.

Planet Plan Sets
EASY SOLAR PERMITTING

**Planet Plan Sets / 866.898.6886 / planetplansets.com**

## Enphase Energy and Solaria Announce AC Module

**[Petaluma and Oakland, CA]** Enphase Energy and Solaria have partnered to produce the Solaria PowerXT-AC model. The ac module integrates Enphase's IQ 7+ microinverter with Solaria's all-black high-power 355 W module. The proprietary PowerXT platform uses Solaria's advanced cell interconnect and module production processes. The IQ 7+ Micro, Enphase's seventh-generation microinverter platform, has advanced Smart Grid features and supports 60- and 72-cell PV modules at up to 440 W with peak output power of 295 Wac. The microinverters are certified compliant with *NEC 2014* and *2017* rapid-shutdown requirements and meet requirements for distributed solar on utility networks included in California's Rule 21 and Hawaiian Electric Company's Rule 14H. Integrators can procure the PowerXT-AC module from Soligent at locations around the US.

**Enphase Energy / 877.797.4743 / enphase.com**
**Solaria / 510.270.2500 / solaria.com**
**Soligent / 800.967.6917 / soligent.net**

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## A Changing Energy Landscape

In a world of changing energy needs, complex utility rates and evolving regulations, the need for adaptable renewable energy solutions is leading the renewable energy conversation. OutBack Power's response is a new class of renewable energy system, the SkyBox™ True Hybrid Energy System. In the context of SkyBox, *true hybrid* refers to not only its integrated design, but also its ability to function as a traditional grid-tied inverter, as a battery-based, grid-connected energy management system or even as a totally off-grid system.

The fully programmable 5 kW SkyBox measures and monitors power to and from any connection point—utility, solar, battery, generator and load—to dynamically optimize energy production and consumption based on an individual owners' energy profile. For owners not yet ready to install a battery-based system, SkyBox can be installed and commissioned without batteries today and will easily accept batteries later, with no retrofitting of the PV system or ac-coupling required.

In addition to offering hybrid flexibility to end-users, SkyBox is designed to take the complexity out of installing and commissioning a battery-based system. Compatible with a wide range of 48 V battery chemistries, installers benefit from the single-box design that eliminates the need for external charge controllers and communications equipment, reducing installation time and cost. A high-voltage 400 Vdc bus supports long array strings, which eliminates the need for rooftop fuses and disconnects, further reducing cost and complexity. Skybox is fully compliant with the grid-support requirements outlined in UL 1741 SA and adopted under California Rule 21 and HECO Rule 14H, thereby eliminating regulatory uncertainty in two of the largest solar markets in the US.

As a member of the Alpha Group of companies, OutBack Power leverages the collective expertise and resources that come from Alpha's more than 40-year history of designing, manufacturing and supporting power solutions for fault-intolerant and mission-critical applications.

*—OutBack Power / Arlington, WA / outbackpower.com*

# Residential Solar-Plus-Storage Systems

While interactive PV system designs are relatively straightforward for most homes, residential solar-plus-storage designs are inherently more challenging. Contractors need to educate customers and understand their project goals, navigate additional design considerations and make informed technology decisions—and all of this must take place in an evolving regulatory environment.

Here I provide residential solar contractors with some guidelines and best practices for designing solar-plus-storage systems that meet or exceed customers' expectations. Though I focus on residential applications, much of the information also applies to commercial projects.

## Define Customer Goals

As for any PV system, contractors need to design solar-plus-storage systems with their customers' goals in mind. While this point may seem obvious, it is too often overlooked in energy storage applications, whose functional versatility is a potential trap for designers.

Residential energy storage systems can provide secure backup power, allow time-of-use bill management or increased PV self-consumption, or even moderate residential demand charges. However, no one battery or battery-based inverter is the ideal tool for every application. To select the best energy storage components, technologies and system architectures, designers must identify and focus on their customers' project goals as early as possible.

Some customers want to add batteries to improve service reliability. They may have experienced a prolonged grid outage in the past, have loads that require secure power, or simply wish to avoid the inconvenience of an outage, even in circumstances where service interruptions rarely occur. When backup power is the primary goal, contractors are designing for peace of mind rather than ROI. While these customers may only realize the value of their energy storage investment on rare occasions, they may be willing to oversize a solar-plus-storage system so they can back up critical loads for a period of days.

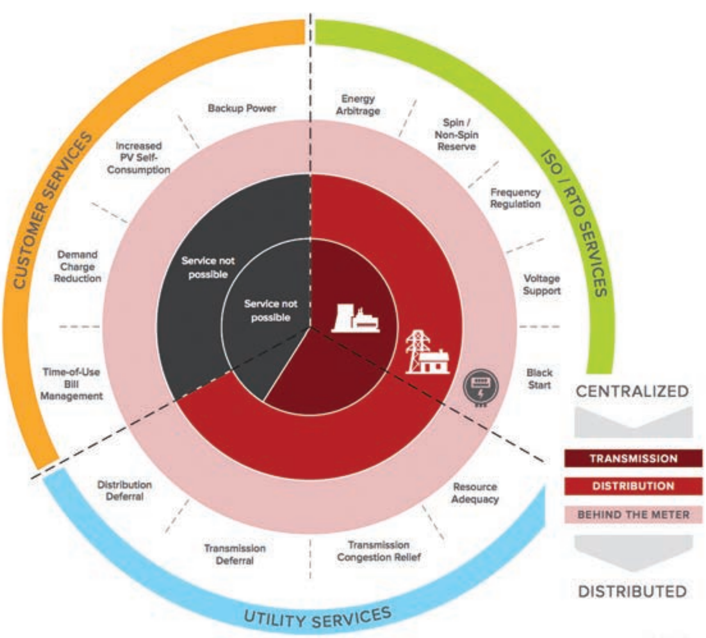
More commonly, customers are interested in a solar-plus-storage system as an investment strategy. In these scenarios, service providers need to determine whether customers are looking to maximize the internal rate of return (IRR) or avoided utility costs. These are two very different goals with meaningful design implications. In a time-of-use bill management scenario, for example, large-capacity batteries tend to maximize revenue available from energy arbitrage while diminishing the IRR, because the equipment costs are high. By comparison, smaller-capacity batteries tend to maximize the IRR, because the equipment costs are low, but offer relatively modest utility savings since they cannot shift much energy in time.

## Understand the Market

Many customers want to have their cake and eat it too—they want a solar-plus-storage system that provides energy security while generating a positive ROI. Though residential energy storage markets in the US are expanding, the market needs to provide the right combination of policies, incentives and rate structures to allow customers to save money while improving service reliability.

Service providers play an important role in determining project feasibility and setting customer expectations. This requires an understanding of utility incentives, rate structures and interconnection requirements; operating cost obligations; risks associated with potential utility policy changes; and any factors that impact a payback analysis, such as cash flows or future

**Customer services** Rocky Mountain Institute has identified four customer-facing use cases for energy storage in behind-the-meter applications.




Courtesy Rocky Mountain Institute

cost savings. Understanding fluctuating market conditions is as complicated as it sounds. However, it is essential to determine final up-front costs and ongoing costs over time.

Anyone who has worked in solar sales knows that many customers who start off interested in PV systems with backup power capabilities ultimately decide to go with a simpler interactive system after considering the costs and financial returns. However, the opposite is true in some states with high levels of solar penetration. In Hawaii and California, for example, some prospective customers become interested in energy storage when they learn it can actually improve PV system economics due to changes in utility rate structures or interconnection policies.

Customers in California, for example, may have access to a Self-Generation Incentive Program (SGIP) for residential energy storage, depending on their utility provider and SGIP reservations. Net Metering 2.0 also requires that solar customers switch to a time-of-use (TOU) rate schedule. Even in situations where incentive program funds are unavailable, this structure may tilt the balance in favor of adding energy storage to an interactive solar system so that it can shift solar production in time to offset energy use during peak pricing periods. Since rate structures vary by utility, solar providers working across multiple service territories also need to adapt project designs to optimize system performance based on each utility's rates and interconnection standards.

## Ensure Adequate Capacity

To properly size battery and inverter capacity, system designers need information about critical loads, the desired duration of autonomous operation and the expected PV system production. They also need as-built electrical diagrams of the home and any existing electrical systems.

Critical loads are any electrical loads that the energy storage system will support in the event of an outage. Ideally, designers should work from an itemized list or spreadsheet identifying all the loads and characterizing them based on utilization voltage, power (or current) ratings, duty cycle (number of operating hours per day) and so forth. Since customers can manage lighting and receptacle loads during an outage based on battery state of charge, designers can rely on generic load assumptions to a certain extent. But it is very important for designers to have detailed information about larger loads, especially nonresistive inductive or capacitive loads. If the energy storage system will support motors or pumps, for example, designers need to know the surge voltage (kV) and ramp rate required at start-up as well as the reactive power (VAR) required to stabilize the load. These ratings are important because the battery-based inverter and energy storage capacity must be adequate to support the maximum expected instantaneous load.

To convert power (kW) to energy (kWh), designers also need to define the expected period of autonomy, be it hours or days. Customers who want to ride out occasional, short-duration outages are candidates for a battery designed to support a few hours of autonomous operations, especially if they are willing to adjust usage based on battery state of charge. Those who wish to prepare for natural disasters, such as a hurricane or earthquake, or who do not wish to moderate usage may be candidates for a battery that supports multiple days of autonomy. The minimum acceptable energy storage capacity is a function not only of the loads (power rating and duty cycle) and customer expectations (length of autonomy), but also of the selected battery technology (allowable depth of discharge [DOD] and degradation rate over time).

If PV is already present or proposed for installation, designers also need to account for hourly solar production when sizing the energy storage system. Industry professionals refer to this as *8,760 data,* because it accounts for every hour of every day for a full year. If these data are unavailable, designers can generate 8,760 data directly, provided they have the following information: PV system capacity (kWdc), module data (manufacturer, model, STC rating), ground-cover ratio (for ground- or flat roof–mounted systems), and array tilt and azimuth. Site address is also critical as this allows the designer to determine design temperatures as well as AHJ permitting, inspection and interconnection requirements.

## Maximize Utility Savings

If the customer's goal is to maximize utility savings or ROI, the battery system designer will need to assess the utility bill in more detail than is typical in a simple net-metered grid-interactive application. In ROI-sensitive applications, designers need the following information from the utility bill: current tariff rate and structure, demand charges (where applicable), energy charges, fixed charges, eligibility criteria, billing period (start and end dates) and address.

If solar is already present or proposed for installation, the designer needs to gather the 8,760 data as well as the system specifications previously detailed. The designer also needs to know the preferred interconnection regime, such as net-energy metering (NEM), non-exporting, or net-energy metering multiple tariff (NEMMT), which allows interconnection of a NEM-eligible generator technology with a non-exporting generator. Energy storage interconnection policies are constantly evolving, so the designer must have access to the utility's latest interconnection policies and rates, as these are critical for maximizing the value proposition.

Even if the above data are unavailable, the designer may be able to recommend the best option for scenarios such as a given tariff rate, PV system capacity or a balance of autonomy and cost. If not, the designer can conduct a gap analysis to determine which pieces of the puzzle need defining before initiating a complete system design.

## Choose Appropriate Technology

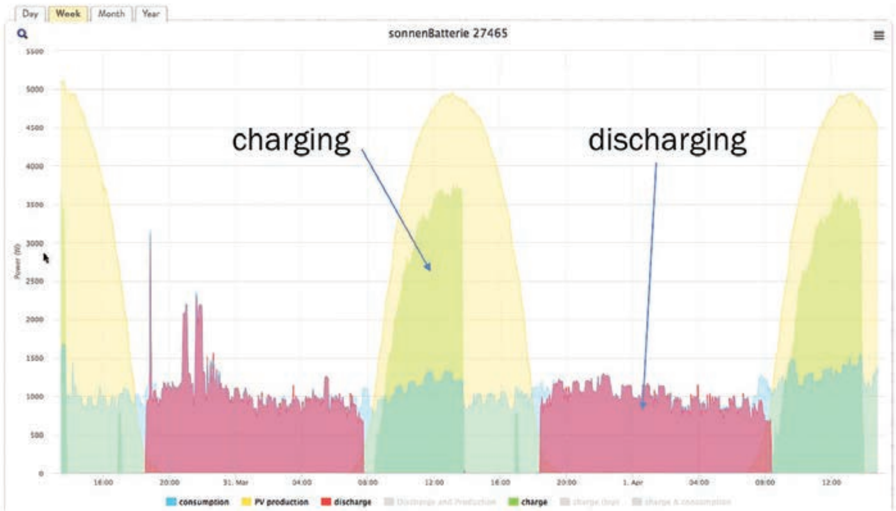
Many residential energy storage vendors offer cookie-cutter battery-in-a-box solutions, often with an integrated inverter. These off-the-shelf energy storage "appliances" can streamline sales and installation. However, system designers still need to evaluate technologies and equipment configurations to ensure that they specify appropriate equipment based on application-specific use cases and installation environments.

To optimize system performance, longevity and cost, for example, designers need to identify the right storage technology. Batteries are broadly categorized as *power type* or *energy type,* depending on their expected discharge frequency and depth. Power-type batteries are ideal for applications with short charge and discharge times; energy-type batteries are ideal for applications with long charge and discharge times.

Designers must also consider operations, maintenance and code compliance. For example, lead-acid batteries require ventilation, temperature-compensated charging, routine maintenance and, potentially, periodic equalization. Lithium-ion batteries may require fire detection and suppression, thermal management and room to expand as their storage capacity degrades. Though flow batteries are rare in the US, this storage technology, increasingly popular in Australia and Germany, requires double containment as protection against electrolyte leaks and spills, as well as the usual clearance for maintenance and access.

Regardless of battery technology, designers need to adhere to the manufacturer's instructions regarding handling, storage, installation, operation and maintenance. It is especially important for designers to evaluate product specifications, including allowable DOD, ac power rating, energy rating (kWh), round-trip efficiency and annual degradation rate. In many cases, the product manufacturer may not provide all of these specifications, making it necessary for the designer to extrapolate them. For instance, the manufacturer may know the dc energy rating of its battery but not the ac rating, in which case the designer needs to adjust the dc rating based on the inverter-charger's round-trip efficiency and parasitic loads, such as controllers or HVAC system, to estimate the ac energy rating. Quality designs will also account for performance changes over time, since round-trip efficiencies may decrease as batteries age.

System configuration is another important design consideration. In an ac-coupled configuration, both the PV array and the battery have a dedicated inverter. In a dc-coupled system, both generator technologies share a single inverter. There are pros and cons associated with each option. AC-coupled configurations provide a lot of design flexibility in terms of generator capacities or future




Courtesy Sonnen

**Energy arbitrage** Utility tariffs with high time-of-use rates—such as PG&E's E-TOU-B tariff—provide opportunities to monetize energy arbitrage. Customers can "buy low" by storing solar-generated energy during off-peak periods and "sell high" later by discharging during on-peak periods.

expansion, but two-inverter solutions tend to be more expensive and have lower round-trip efficiencies. One-inverter dc-coupled configurations are not only less expensive and more efficient, but also tend to simplify system design and installation; in terms of generator capacities and future expansion, however, they are relatively inflexible.

### Design for Safety

Like any electrical system, energy storage systems are subject to electrical and fire safety codes and standards. However, this relatively new market presents unique hazards and integrates relatively new technologies, so the relevant codes and standards are constantly evolving in response to feedback from the field and concerns from industry stakeholders.

To address electrical safety in the emerging energy storage market, the 2017 edition of the *National Electrical Code* introduced Article 706, Energy Storage Systems. While the *NEC* mentions batteries in many other articles—most notably, Articles 480 and 690—the requirements in Article 706 supersede those found elsewhere wherever requirements differ. Since Article 706 is new in *NEC 2017,* the *Code*-making panel will likely introduce meaningful revisions with each development cycle until the market and technologies mature.

The fire safety standards for energy storage are even less developed. The National Fire Protection Association (NFPA) is currently developing NFPA 855, Standard for the Installation of Energy Storage Systems. This new standard will be one of the first to specifically address potential fire hazards associated with lithium-ion batteries.

Regardless of the evolving electrical and fire safety standards for batteries, contractors should always follow these minimum best practices for designing residential energy storage systems with safety in mind. Design systems with adequate working clearance in and around the battery, as required by the manufacturer's instructions and *NEC* Article 110. If the battery chemistry is flammable, keep an appropriately rated fire extinguisher in an accessible location. In the event of a line-side connection, engage a licensed professional engineer to document and stamp the design. Wherever possible, use equipment listed to UL 9540, Standard for Energy Storage Systems and Equipment.

Using products or systems listed to UL 9540 minimizes component compatibility issues in the field, reduces custom design and engineering requirements, and limits liability. If the design calls for equipment that is not UL 9540 listed, ensure that all components—battery enclosures, charge controllers, bidirectional inverter-chargers, transfer switchgear, energy management system, critical load panels and overcurrent protection devices—and conductors are properly rated and sized. Confirm that ground-fault protection meets *NEC* requirements and that the battery and inverter-charger are properly integrated for power, communications and controls.

### Comply with AHJ Requirements

Whether designing a system for security, ROI or other customer-driven considerations, the designer must ensure that the end result satisfies all utility policy and interconnection requirements. These requirements can vary depending on whether the energy storage system exports power.

The following utility policies generally apply to non-exporting backup-power energy storage systems. When the grid is available, all grid-export capabilities must be disabled, via either a relay protection device or a transfer switch; the grid and any on-site PV are allowed to charge the battery. When the grid is unavailable, a manual or automatic transfer switch located inside or outside the inverter must isolate the system from the utility; once isolated, the battery can discharge to loads.

Utility requirements for net-metered energy storage systems vary. A new policy in California allows solar-plus-storage systems to interconnect in much the same way as an interactive PV system, provided that the system charges the battery from renewable energy sources only. In this scenario, solar-plus-storage systems are not subject to non-export interconnection rules because the utility knows that solar is the original source of all power exports. Since energy storage is an accessory to the PV system, it makes no difference whether PV-generated energy exports directly to the grid or first detours through the battery.

From a financial perspective, NEM is most advantageous for solar-plus-storage customers because this interconnection agreement allows developers to enhance the traditional net-metering value proposition. In a time-of-use regime, service providers can optimize the value derived from a solar-plus-storage system by storing off-peak solar energy in the battery for export during peak-pricing periods. As long as solar is the only battery-charging source, the customer can claim a 30% federal tax credit on the entire solar-plus-storage system.

While it is still early days for residential energy storage, many analysts expect that other states will eventually follow California's lead in terms of incentives, rate structures and interconnection policies. If so, residential solar contractors with the technical and sales capabilities to offer energy storage solutions can unlock an additional revenue stream for their business and customers.

*—Josh Weiner / SepiSolar / Fremont, CA / sepisolar.com*

Courtesy SunPower

Since Bell Labs introduced the crystalline silicon solar cell to the world in 1954, the technology has enabled exploration in space and transformed electrical power systems back on earth.

By Blair Reynolds

# EVOLUTION of c-Si PV Cell Technologies

A solar cell is an electronic device that directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electrical power. This process requires a material in which the absorption of light raises an electron to a higher-energy state so that it can break free from its atomic structure and move around. Certain metals and semiconductors exhibit this trait, known as the *photoelectric effect.* Once the higher-energy electron is free, it must be able to move from the solar cell into an external circuit to dissipate its energy. It then returns to the solar cell to complete the circuit.

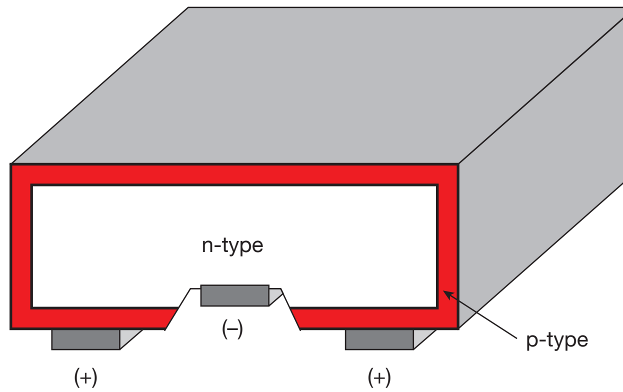
Sunlight is a form of electromagnetic radiation, and the visible light that we see is a small subset of the total incident energy the sun emits. In 1905, while studying the photoelectric effect, Albert Einstein described light as packets or particles of energy, today known as *photons.* Even after Einstein explained the physics of the photoelectric effect, it took many years for a practical electrical-generation application of the technology to evolve.

In this article, I briefly explore the history, anatomy, physics and lexicon of crystalline silicon (c-Si) PV cells. I then consider the evolution of modern high-efficiency c-Si PV cells, which is a function of important manufacturing advances as well as innovations in solar cell technologies. Finally, I consider some of the most promising paths forward to higher-efficiency and lower-cost c-Si PV modules for terrestrial applications. As this story will tell, it can take a lot of time—and a measure of good luck—for a solar cell technology to journey from the research laboratory to a format that facilitates mass production and a cost structure that enables commercial market opportunities.

## EARLY HISTORY

The solar industry widely recognizes Bell Labs as the inventor of the modern-day solar cell. As solar historian John Perlin details in *From Space to Earth* (see Resources), Bell Labs tasked a group of scientists with developing a source of freestanding power as an alternative to traditional dry-cell batteries, and they began experimenting with photosensitive materials in 1952. After their initial attempts to improve the power output of selenium-based solar cells fell short, researcher Gerald Pearson discovered that silicon-based semiconductors, which Bell was developing for use in telephone transistors, provided a much more efficient base material for PV cells.

In 1954, Bells Labs announced its development of the Bell Solar Battery, an n-type, rear-contact silicon solar cell, shown in Figure 1, with a conversion efficiency of 6%. In spite of media praise for the invention, the company struggled to find a serious market for this device outside of novelty items, such as toys or radios run on solar. The success of the semiconductor transistor, which rapidly achieved economies of scale, ultimately made the Bell Solar Battery obsolete for the telecommunications industry at that time.



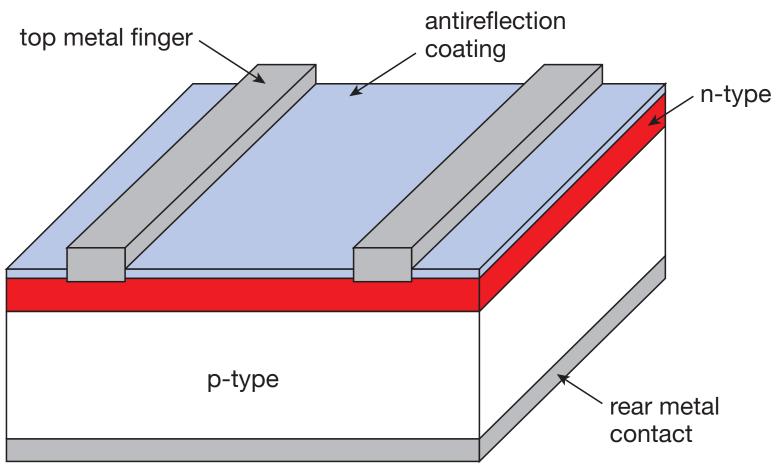

Courtesy Martin Green

**Figure 1** This illustration shows the cell structure Bell Labs used in 1954 for its Bell Solar Battery, the first modern silicon cell.

The space race was a critical turning point for silicon-based solar cells, which would subsequently take off—literally. On March 17, 1958, the US Navy launched the *Vanguard 1*, the fourth-ever artificial earth orbital satellite and the first to include a PV power source. Whereas earlier satellites relied on battery power only and had a mission duration of days, the solar- and battery-powered *Vanguard 1* remained in service for more than 6 years. The ability to extend the useful life of orbiting satellites by allowing the sun's energy to recharge onboard batteries was critical to success in space-based applications.

Established in late 1958, NASA demonstrated an interest in photovoltaics, spurring technological advancements that would lead to the development of more-powerful and more-reliable PV cells. With further experimentation and refinement, researchers drastically improved solar cell efficiency to around 14% by 1960. Scientists discovered, for example, that antireflective (AR) coatings on the front surface of the PV cell helped improve the absorption of light compared to bare silicon, which otherwise has a surface reflectance of over 30%. Other advancements, such as applying electrical contacts to the front of the cell rather than the rear, improved manufacturing speed and cost.

In his history of c-Si cell technologies (see Resources), Martin Green notes that while the basic cell design for space applications, shown in Figure 2 (p. 20), remained largely unchanged for about a decade, a number of improvements came about in the 1970s. Researchers discovered, for example, that adding a thin aluminum layer to the back of the c-Si PV cell created a back-surface field that delivered a significant boost in performance. Not long afterward, COMSAT Laboratories boosted performance further by chemically etching the surface of the c-Si PV cell to produce pyramidal structures that reduced reflection. By



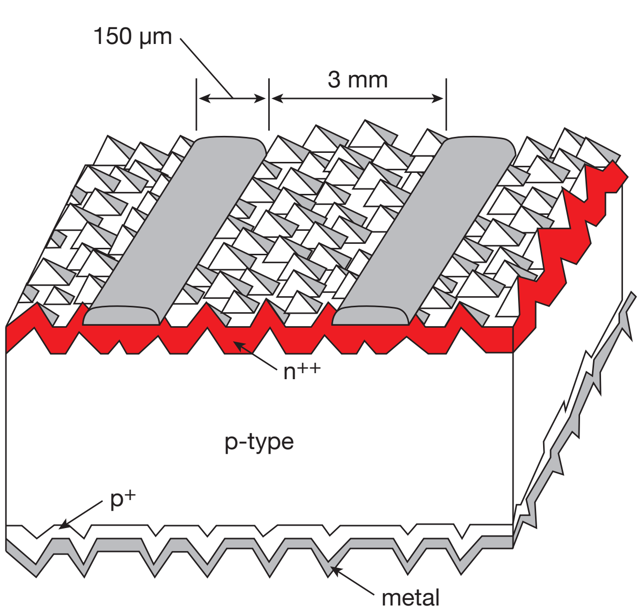

Courtesy Martin Green (2)

**Figure 2** This illustration shows the basic c-Si cell design used for space-based applications throughout the 1960s.

1974, terrestrial cell performance had achieved conversion efficiencies of more than 17%.

In 1975, Spectrolab pioneered a screen-printing process for applying front metal contacts to the solar cell, using a metallic paste forced through a patterned template with a squeegee, a process similar to applying graphics to T-shirts. As crude as it may sound, this development ultimately led to dramatic manufacturing cost reductions and enabled PV technologies to become practical in terrestrial applications. Interestingly, oil and gas companies were some of the earliest adopters of terrestrial solar, deploying PV technology for offshore drilling wells. The process of screen-printing fingers on the front surface of a solar cell, such as the one shown in Figure 3, proved so effective that it is still in use today in large-scale c-Si PV manufacturing operations.

**Figure 3** Researchers had implemented the main features of commercial c-Si PV cells, such as surface texturing and screen-printed metallic contacts, by the mid-1970s.




## ANATOMY OF A MODERN C-SI CELL

The structure of a modern c-Si solar cell is a stack of layers built up on either side of a silicon substrate known as the *base layer.* Silicon crystals are formed by growing a single continuous crystal ingot (monocrystalline silicon) or by producing a solid block of many different crystals (multi-crystalline silicon). The base layer of the solar cell begins as a thinly sliced wafer of c-Si that is charged either positively (p-type) or negatively (n-type). Manufacturers typically dope the p-type wafer with boron, resulting in a net positive charge. Conversely, introducing a negatively charged impurity such as phosphorous results in an n-type wafer with a net negative charge. (P-type solar cells are the most common commercial variety and have held the largest market share among all PV technologies for the last four decades.)

The front surface of the wafer, known as the *emitter layer*, is formed by injecting an extremely thin layer of dopants, which have a charge opposite that of the base layer. Since the near front surface absorbs a high percentage of light, the primary function of the emitter layer is to absorb incident photons, which in turn generates a pair of oppositely charged carriers. The intersection of the oppositely charged emitter layer and the base layer is known as the *p-n junction.* This is essentially two physically adjoined layers of silicon crystal with opposite charges, which help separate carriers based on their natural magnetic field.

Bare silicon is highly reflective. Therefore, to reduce the probability that a photon is reflected off the solar cell, manufacturers typically apply two additional layers to the front surface. First, they apply a prismatic texture, resembling miniature pyramids, to redirect photons toward the cell, thereby reducing the likelihood of reflecting light. Second, they typically apply a silicon-nitride AR coating, which helps prevent the unwanted reflection of light in the useful spectrum and acts as an effective front-surface passivation technique.

Finally, they apply metallic contacts to collect the positive and negative carriers. In a traditional c-Si solar cell, to form the rear contact, manufacturers screen-print a continuous solid layer of aluminum paste to the rear side of the solar cell. Also using a screen-printing process, they apply a silver paste to form a grid pattern on the front CONTINUED ON PAGE 22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and String Inverter types
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Code compliance
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Rapid Shutdown | String Inverter Solutions | Battery Combiners
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surface of the solar cell. The size, shape and placement of these grid lines is extremely important to cell performance. On the one hand, the grid lines block sunlight from reaching the surface of the cell, so they require sufficient spacing between them. On the other, if you space the grid lines too far apart, losses may increase due to the inherent resistance of the cell's semiconductor material.

**The electric field that exists at the p-n junction separates the light-generated carriers.**

### PHYSICS OF A SOLAR CELL

At its essence, the job of a solar cell is to generate a pair of oppositely charged light-generated carriers and transport these carriers so they can dissipate their power in an external load. As detailed on the PV Education Network website (see Resources), solar cells operate according to four basic steps: Generate light-generated carriers, collect light-generated carriers to generate a current, generate a large voltage across the solar cell, and dissipate power in the load and in parasitic resistances.

The generation of current in a solar cell, known as the *light-generated current,* involves two key processes. The first is the absorption of incident photons to create a pair of carriers known as an *electron-hole pair.* If an incident photon has a high enough energy when it impacts an atom in the silicon crystal, it can knock an electron loose from orbit around the silicon atom within the crystal. Once the electron is loose, it is free to move about the semiconductor and participate in conduction. However, when the photon knocks the electron loose from the orbit of the silicon atom, that leaves behind an empty space for another electron to fill. An electron from a neighboring atom can move into this empty space. When this electron moves, it leaves behind another space and so forth.

This continual movement of the space, called a *hole,* marks the path of a positively charged particle through the crystalline structure. A moving hole is analogous to a bubble in a liquid, except that the crystalline structure does not move as a liquid does. Rather, it is the hole that moves. Because both the electron and the hole can participate in conduction, they are called *carriers.* Since carriers are moving through a solid crystal material by joining and rejoining neighboring silicon atoms, their path is not as direct as one might think. They tend to bob and weave as they make their way toward the oppositely charged surface of the solar cell.

Before a carrier is collected or swept across the p-n junction, it is not extremely stable. Therefore, the carrier will exist only for a limited period of time, referred to as the carrier *lifetime,* before recombining with a silicon atom. If the carrier recombines, then the light-generated electron-hole pair disappears without generating current or power.

The second key process for generating current in a solar cell is to prevent carrier recombination. This is accomplished by forming a p-n junction to collect the carriers, which helps to separate the electron from the hole spatially. An electric field that exists at the p-n junction separates the carriers. If the light-generated minority carrier reaches the p-n junction, the electric field sweeps it across the junction, and it becomes a majority carrier. Connect the emitter and base layers, and the light-generated carriers flow through the external circuit, putting the solar cell into operation.

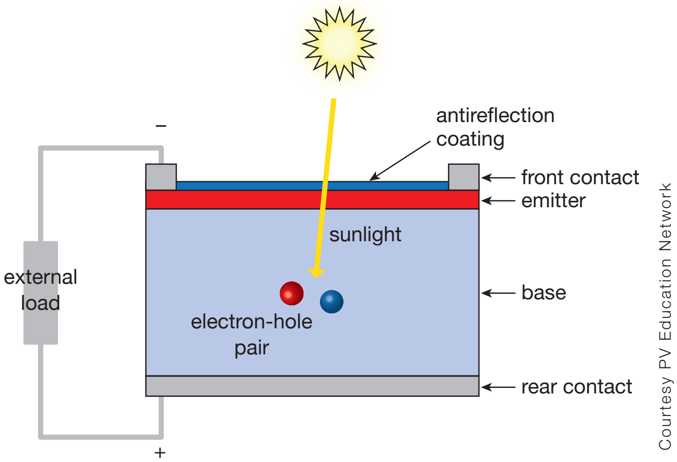
### ADVANCES IN C-SI PV

Cell architecture advancements in the 1980s and 1990s propelled c-Si PV technologies to conversion efficiencies that researchers had previously thought unimaginable. As early as the late 1970s, researchers were experimenting with a technique known as *surface passivation,* whereby they applied an oxide layer to the surface of the solar cell to reduce carrier recombination and improve open-circuit voltage levels. Green's research group at the University of New South Wales (UNSW) achieved such success with surface passivation techniques that in 1985 it produced the first silicon cell to exceed 20% efficiency. This breakthrough was so extraordinary that Green has likened the accomplishment to breaking the 4-minute-mile mark in running.

While the theoretical maximum conversion efficiency for single-junction silicon solar cells is around 29%, industry experts such as Richard Swanson, SunPower's retired founder, have concluded that the practical conversion efficiency limit in commercial mass production is likely in the 24%–25% range. (See the SunPower white paper in CONTINUED ON PAGE 25

# Glossary of c-Si PV Terminology

While PV power systems are elegant in their simplicity, the material science behind module technologies and manufacturing is considerably more complex. Today, you do not need to be a rocket scientist to design and install high-quality PV power systems. In the 1960s and 1970s, however, most of the scientists and researchers who discovered techniques for improving c-Si PV cell performance were working with rocket scientists to improve the performance of satellites. This glossary defines some of the technical terms I use throughout this article to describe c-Si PV cell technologies and module construction.




**Basic c-Si PV circuit** Light shining on the solar cell raises an electron to a higher-energy state, freeing it to dissipate its energy in an external circuit.

**Base layer:** The silicon substrate, the foundation for the layers that form a solar cell.

**Carriers:** Light-generated carriers are either electrons or holes (missing electrons) in a solar cell's atomic structure.

**Dopants:** Impurities that have a net negative or positive charge as compared to silicon. The most common dopants used in modern c-Si solar cells are phosphorus and boron.

**Doping:** The technique of intentionally adding a concentration of impurities to a semiconductor material to vary the electric charge.

**Electron:** A negatively charged subatomic particle. An electron can be either free, meaning not attached to any atom, or bound to the nucleus of an atom.

**Electron-hole pair:** Incident light that impacts a solar cell with sufficient energy will dislodge an electron from its bond in the crystalline structure and thereby create a *hole.* The negatively charged electron and positively charged hole are a pair of carriers that provide the basic constituents for electric current flow in the solar circuit.

**Emitter layer:** The layer of a c-Si cell that is exposed to sunlight. The emitter layer absorbs incident photons and emits charged particles known as *carriers.*

**Fingers:** Metallic contacts that are typically screen-printed on the front surface of a c-Si cell.

**Hole:** An empty space in an atom's structure for an electron to fill. For simplicity, often the hole is visualized as a positively charged particle that can move through the crystal structure.

**Lifetime (of a carrier):** The length of time that a free-moving carrier can exist in the solar cell structure before it is reabsorbed.

**Light-generated carriers:** Either electrons or holes, which are essentially missing electrons, in a solar cell's atomic structure.

**Majority carrier:** A carrier that has a similar charge compared to the surrounding material, such as electrons in n-type material and holes in p-type material.

**Minority carrier:** A carrier that has an opposite charge compared to the surrounding material, such as electrons in p-type material and holes in n-type material.

**N-type silicon:** Silicon doped with an impurity that results in a net negative charge when compared to pure silicon. Negatively charged silicon is typically doped with phosphorous.

**P-type silicon:** Silicon doped with an impurity that results in a net positive charge when compared to pure silicon. Positively charged silicon is typically doped with boron.

**Photoelectric effect:** The release of electrons from certain metals and semiconductors in response to light.

**Photons:** Packets or particles of energy contained in electromagnetic radiation, which includes the visible light spectrum.

**P-N junction:** The intersection of the base layer and the oppositely charged emitter layer. P-N junctions form the basis not only of solar cells, but also of many other electronic devices such as LEDs, lasers, photodiodes and bipolar junction transistors.

**Single-junction cell:** Solar cells with a single p-n junction, as opposed to tandem- or multi-junction cells with two or more p-n boundaries that respond to different wavelengths of light.

**Surface passivation:** The application of an oxide layer to the surface of the solar cell to reduce carrier recombination.

**Terrestrial photovoltaics:** PV devices designed for earth-based rather than space-based applications.

**Wafer:** A thin slice of c-Si that forms the substrate of the solar cell. ●

Resources.) To put the cell technology advances of the 1980s and ’90s into context, consider that researchers produced the first 24% efficient silicon cell in 1994 and extended this record to 24.5% by 1998. Fast-forward to January 2018, when Germany’s Institut für Solarenergieforschung announced that it had achieved a new international conversion efficiency record for a single-junction silicon cell of 26.1%. (See the *PVTech* article in Resources.)

The fact that it took two decades to improve single-junction cell efficiencies in the laboratory by 1.6% illustrates just how difficult it is to achieve additional incremental improvements in silicon cell performance. It also illustrates just how advanced silicon cell technologies were by the 1980s and ’90s. In fact, many of the high-efficiency cell technologies in mass production today date to this period of research and innovation. The most impactful advancements during this era were improvements in the manufacturing process, which drove PV module costs down from around $70 per watt in 1978, drawing a well-documented comparison to Moore’s Law.

**Many high-efficiency cell technologies in mass production today date to the 1980s and ’90s.**

**Interdigitated back contact cells.** Researchers at Stanford University developed the first high-effciency rear-contact silicon cell in the 1980s. Originally designed for concentrating PV applications, the Stanford cell was unusual in that it placed both the positive and negative contacts on the rear surface of the cell. On the face of it, this design is similar to the original Bell Solar Battery. However, the two cells operate very differently. By using extremely high-quality n-type silicon, Stanford’s rear-contact cell allowed light-generated carriers located near the top surface of the cell to travel to the rear contacts on the bottom surface of the cell.

To maximize the efficiency of a solar cell, the carriers must travel across the p-n junction as quickly and efficiently as possible. One simple but expensive way to improve carrier lifetime is to use ultra-purified silicon wafers, as this reduces the likelihood that a carrier will interact with impurities in the crystal structure. This is especially true for rear-contact solar cells, such as the Stanford cell, which need to transport carriers a further distance.

In 1988, the rear-contact cell achieved a conversion efficiency of 22%. Today, the industry refers to this silicon cell

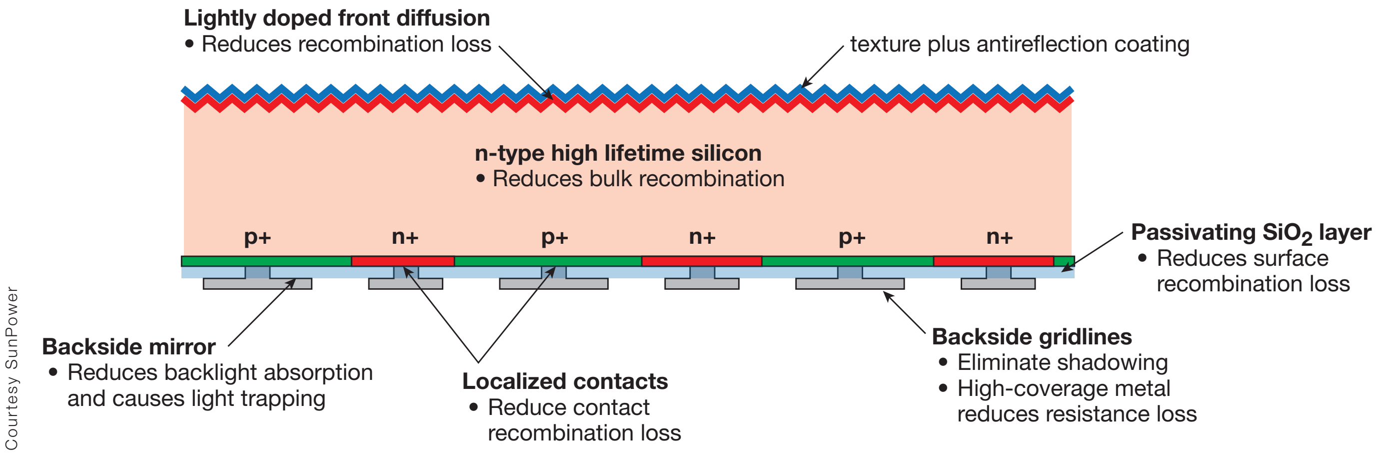
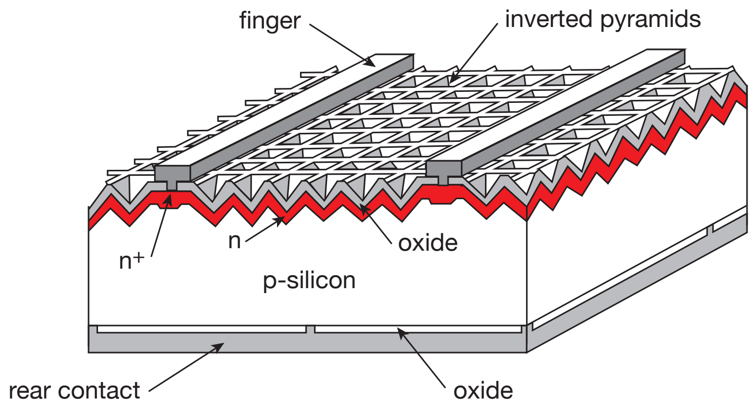



**Figure 4** This figure from a SunPower white paper (see Resources) details some of the techniques the company uses to improve the performance of its high-efficiency IBC cells. The company has broken the 25% efficiency barrier at the cell level and the 24% barrier at the module level, and is approaching 23% efficiency in commercial mass production.

design as the *interdigitated back contact* (IBC) architecture due to the repeating pattern of positive and negative contacts on the backside of the cell. Incorporated in 1985 and publicly traded since 2005, SunPower is notable for having commercialized and improved upon this high-efficiency n-type silicon cell design, shown here in Figure 4. Trina Solar and Yingli Solar have both announced IBC cell efficiency records in recent years.

**Passivated emitter and rear cell.** For a period of time, it appeared as though rear-contact silicon cells had an insurmountable performance advantage over front-contact cell architectures. The latter, after all, must overcome the fact that metal contacts shade about 5% of the front cell surface. In the early 1990s, however, the research group at UNSW discovered a way to improve silicon cell efficiency. While experimenting with lasers to scribe and passivate the front cell surface, the Australian team discovered that cell performance improved when they applied higher concentrations of dopants precisely underneath the areas where they would later apply metal contacts.

The process of selectively doping cell areas effectively created a new solar cell category: selective emitter solar cells. The most common cell architecture in this category is the *passivated emitter and rear cell* (PERC) technology, which UNSW successfully demonstrated in 1989. The team started by combining, refining and building upon earlier technology advancements that improved the cell's ability to capture light, such as front-surface texturing and using an AR coating. Its novel advancement was to use lasers to deposit much higher concentrations of phosphorous and boron selectively and accurately under the metal contact areas. The team's 1989 PERC solar cell, shown in Figure 5, demonstrated a conversion efficiency of 22.8%.




Courtesy Martin Green

**Figure 5** The PERC cell that the University of New South Wales pioneered in the late 1980s is now becoming a mainstream technology in commercial mass production.

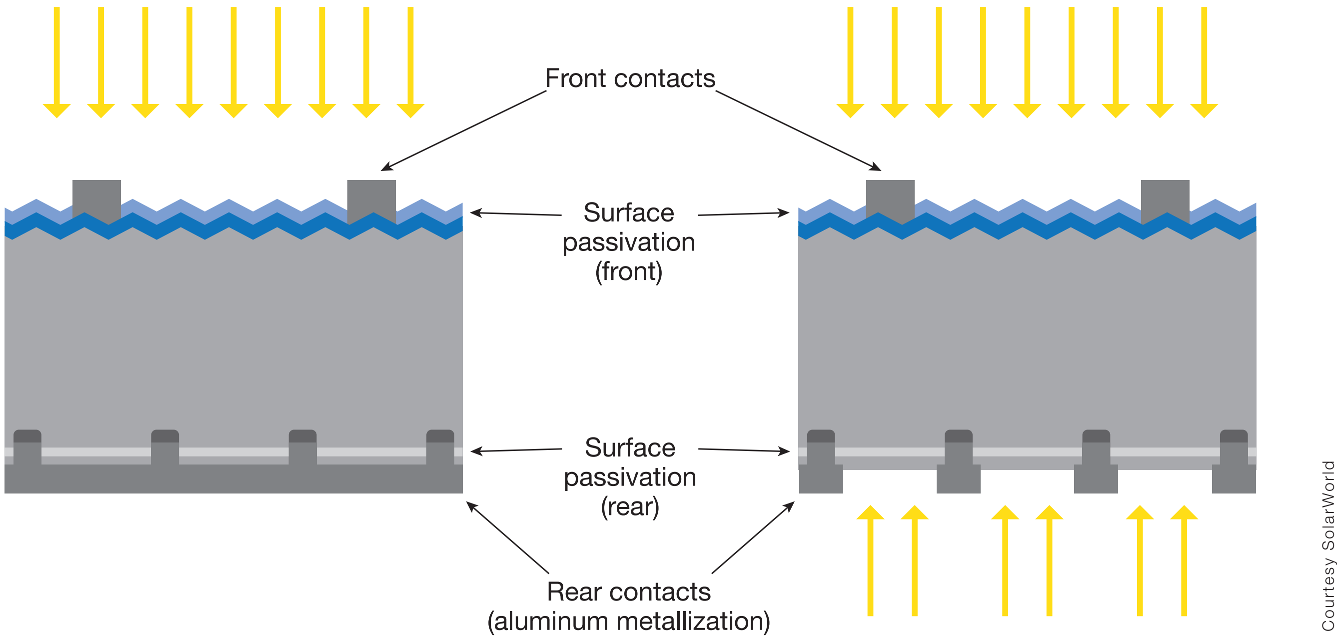



**Figure 6** PERC cells are inherently bifacial. Moving from a fully metallized rear electron (on left) to one that is selectively metallized (on right) allows additional energy capture from light reaching the backside of the cell.

The selective doping process improves performance by generating an additional electromagnetic pull in the crystalline structure that encourages carriers to travel to the exact locations where the circuit can use them. Today, the industry considers PERC architecture one of the most cost-effective ways to produce high-efficiency solar cells. Manufacturers with PERC modules in commercial mass production include Aleo, LONGi Solar, SolarWorld and Trina Solar.

**Passivated emitter rear locally diffused cell.** Not long after documenting the PERC architecture, the UNSW team announced that it had achieved a new world record for a single-junction silicon cell efficiency. The team had improved on its PERC design by laser-embedding tiny, highly doped dots on the rear surface of the cell rather than using a continuous metallic contact. In so doing, it was able to produce a 24% efficient solar cell in 1995 and extend the efficiency record for a single-junction c-Si solar cell to 24.5% by 1998—a record that stood until 2014.

The UNSW team dubbed its new architecture *passivated emitter rear locally diffused* (PERL), since it uses local diffusion at the rear-point contact to help collect light-induced carriers and reduce contact resistance. While the PERL architecture is extremely efficient, this cell technology and other specialized selective emitter techniques have yet to achieve commercialization due to the extremely high costs associated with the manufacturing process. However, the UNSW team made its mark on history, as PERC technology has become increasingly popular in both monocrystalline and multi-crystalline PV cell production.

## WHAT LIES AHEAD?

It is very difficult to improve silicon cell efficiency while reducing costs. Consider that it has taken manufacturers more than 20 years to commercialize some high-efficiency cell architectures. This speaks largely to the difficulty of designing affordable, reliable and repeatable manufacturing techniques that utilize existing equipment and supply chains as much as possible. While IBC and PERL are good technologies for improving cell efficiency, they may not be the most promising options for commercial mass manufacturing because of the higher costs associated with the more-complex production processes. As a result, most manufacturers are looking to improve module output based on existing cell technologies, since these efforts require much lower investments.

**Half-cell modules.** A general manufacturing trend in the industry, going back several decades, is to slice as many silicon wafers as possible from a single ingot, resulting in increasingly thin wafers. Since cells are susceptible to breakage in the production process, there is an inherent tradeoff between saving material cost during production and incurring material cost associated with broken and scrapped cells. One clever method discovered for reusing broken silicon cells is to trim them in half for use in half-cell PV modules. Half-cut cells generate half the current of a standard cell, which reduces resistive losses in the interconnecting busbars within the module. Reducing internal resistance between the cells increases module power output. As a result, manufacturers today CONTINUED ON PAGE 30

can increase module power output by 5 W–10 W, potentially at a lower cost per watt, by intentionally cutting cells in half. Manufacturers commercializing half-cell module designs include JinkoSolar, LONGi Solar, Mitsubishi, REC Solar and Trina Solar.

**Bifacial modules.** The global uptick in PERC module production is likely to lead to a future increase in the production of bifacial modules. As shown in Figure 6 (p. 28), cell manufacturers can produce bifacial solar cells by adding just one processing step to the standard PERC cell production line. Bifacial modules convert light captured on the backside of the module into electrical power, which could increase energy captured in the field by 10%–15% with only a modest increase in manufacturing and installation costs. (See "Bifacial PV Systems," *SolarPro,* March/April 2017.)

Module manufacturers often use a glass-on-glass package for bifacial PV cells rather than the usual glass-on-film package. Bifacial PV systems also require specialty racking systems and unique mounting considerations to capture the maximum bifacial benefit. This bifacial ecosystem is emerging now. Over the last few years, PV module glass suppliers have begun offering ultra-thin PV glass (<2 mm thick), which reduces the weight of the resulting glass-on-glass module. Mounting system manufacturers are now offering specialty bifacial mounting systems, including single-axis trackers for large-scale PV power plants. Module manufacturers commercializing bifacial PV modules include LG, LONGi, SolarWorld, Sunpreme and Yingli Solar.

**Multi-junction cells.** Another way to improve cell performance is to stack multiple p-n junctions to selectively filter out light passing through the cell based on its energy level. For example, the manufacturer can tune a p-n junction near the top surface of the solar cell to absorb more light in the blue spectrum and a p-n junction toward the rear of the cell to absorb more red-spectrum light. Multi-junction cell designs have been around for decades and have carved out a niche in space applications and in concentrating PV. However, manufacturers have struggled to find commercial applications for this cell technology in conventional terrestrial applications due to prohibitively high manufacturing costs.

This is beginning to change, as it is increasingly common to see PV cell designs with additional p-n junctions built by depositing thin-film materials on a c-Si base layer. These so-called *hybrid* or *heterojunction* solar cells can take advantage of many of the benefits of thin film's light-absorbing properties at only a fraction of the cost of building a pure c-Si multi-junction solar cell. The multi-junction cell trend will likely evolve as researchers and manufacturers learn more about perovskite materials, which some have dubbed a "wonder material." Greentech Media reports (see Resources) that Oxford PV claims to have achieved 27.3% efficiency using a perovskite-silicon tandem junction cell technology and believes the technology is capable of breaking the 29% silicon cell efficiency limit. Since perovskites are affordable and can be tuned to low-energy wavelengths, these materials could begin to replace the top thin-film layer in heterojunction cells as they make their way into commercial production.

**Half-cut cells generate half the current of a standard cell, reducing resistive losses inside the module.**

While multi-junction perovskite cells are admittedly complex, this is just one example of the exciting work under way to develop higher-performing silicon cells. As new cell technologies come to market, researchers can optimize PV module encapsulation materials to better match the light-absorption capabilities of these new cell designs. Each marginal increase in module output and efficiency is important because it ultimately serves to reduce the per-watt costs associated with a whole range of project variables, from transportation to land acquisition to the entire BOS ecosystem.

## CONTACT

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# Solar Power International 2018 PREVIEW
## Vendor and Equipment Highlights

By David Brearley

After a two-year absence, SPI 2018 returns to Southern California for a 4-day residency at the Anaheim Convention Center, September 24–27.


Courtesy PlusStudios

Produced by Solar Energy Trade Shows, Solar Power International (SPI) is a collaboration between the Smart Electric Power Alliance (SEPA) and the Solar Energy Industries Association (SEIA). Co-located events include Energy Storage International, Hydrogen + Fuel Cells North America and the Smart Energy Microgrid Marketplace. With more than 620 confirmed exhibitors and over 1,500 companies already represented, the producers hope to draw 20,000 industry professionals to Anaheim. If attendance exceeds expectations, as was the case in Las Vegas in 2017, SPI will have achieved 5 consecutive years of sustained growth.

SPI 2018 attendees can expect to find more technologies and services showcased on the expo floor than ever before, with dedicated pavilions or halls for hydrogen fuel cells, smart energy microgrids, software, energy storage, and commercial and industrial solutions. The expo floor will include dedicated areas for startups, poster presentations and networking. It will also host multiple trainings, receptions and happy hours. Away from the expo hall, attendees can choose from 100-plus educational sessions and a half dozen special events, including a block party, golf tournament, fun run and solar job fair. Educational opportunities include pre- and post-conference workshops, as well as concurrent sessions covering a wide range of topics such as asset management and finance, grid modernization and others. With so much to choose from, SPI attendees would be smart to prioritize their needs and plan their schedules in advance.


Because there is never enough time to take everything in—and some people will not be able to make the trip—this article showcases ten vendors entering SPI with new products, services or announcements, as well as an off-site documentary film screening. Some of these items debuted in June at Intersolar North America. However, companies generally save their biggest North American market announcements for SPI. So book your flight to LAX or John Wayne Airport and get those tickets to Disneyland.

## ABB • BOOTH 2604

Headquartered in Zurich, Switzerland, ABB is a multinational corporation with four global business divisions: power grids, electrification products, industrial automation, and robotics and motion. After acquiring Power-One in 2013, ABB based its US solar inverter operations in Phoenix, Arizona, where it employed as many as 450 people. In response to challenging market conditions, however, the company laid off its US solar manufacturing employees in 2016, moving these jobs to Latvia and Italy. With this restructuring in its rearview mirror, ABB has rebuilt its North American solar inverter portfolio from the ground up. In March, the company introduced a new residential single-phase inverter line that includes five power ratings between 3.3 kW and 6.0 kW. The line is compatible with Tigo's TS4 optimizer platform for rapid-shutdown compliance. In June, it introduced its newest commercial 3-phase string inverter, the 60 kW TRIO-TM-60. Both inverter


**ABB 1,500 Vdc 185 kW string inverter**

platforms are listed to UL 1741 SA and are Rule 21 compliant. ABB's best new inverter product may be yet to come to North America. At Intersolar Europe, the company took home an innovation award for the PVS-175-TL, a 1,500 Vdc–rated string inverter for small- or large-scale ground-mount applications capable of delivering 185 kW of active power.

ABB / abb.com/solarinverters


**Aurora software platform**

### ALSOENERGY • BOOTH 1420

Founded in 2007 and headquartered in Boulder, Colorado, AlsoEnergy provides software platforms and technology solutions for monitoring and controlling energy production assets. Ranked by Greentech Media as the top independent solar monitoring vendor in the US commercial market, AlsoEnergy provides standardized data acquisition systems, custom-designed supervisory control and data acquisition (SCADA) solutions and California Independent System

**AlsoEnergy PowerTrack monitoring**

Operator (CAISO)–compliant RIG solutions. After introducing its PowerTrack platform in 2009, AlsoEnergy expanded its portfolio and customer base by acquiring DECK Monitoring in 2013. Fast-forward 5 years and AlsoEnergy is once again in mergers and acquisitions mode. In July, AlsoEnergy acquired the assets of another US solar monitoring pioneer, Draker Corporation, and announced a partnership with skytron energy, a leading solar monitoring company in Europe. These moves strengthen AlsoEnergy's solutions portfolio and global footprint. At SPI AlsoEnergy will showcase its monitoring, control and performance analysis solutions, including PowerCMMS, a computerized maintenance-management module for PowerTrack that centralizes plant operations and analytics.

AlsoEnergy / 866.303.5668 / alsoenergy.com

### AURORA SOLAR • BOOTH 138

San Francisco–based solar software developer Aurora Solar provides a cloud-based PV system sales and design platform, Aurora, which streamlines and automates everyday activities. Depending on their subscription plan, solar companies can use Aurora as a sales platform only or as an integrated sales and engineering platform. With an address and an electricity bill, Aurora users can determine a site's solar potential, design the optimal photovoltaic system, perform financial analysis and create a beautiful sales proposal in about 10 minutes. Users with access to the engineering package can generate single-line diagrams exportable to ArcGIS, AutoCAD, SketchUp or Visio. This version of the software also verifies *NEC* compliance and autogenerates a bill of materials and a detailed cost breakdown. Annual subscription plans cost $135 or $220 per user per month for the basic (sales) or premium (sales and engineering) license, respectively. With 5 years of experience to draw from, Aurora Solar is redesigning its popular software platform from the ground up, incorporating features and capabilities designed to help users sell more solar. In addition to simplifying and streamlining the platform, the developers are adding new tools, such as automated obstruction detection and auto-stringing, to speed up users' workflow. They are also scaling up project capacity support capabilities. Aurora users will soon be able to design multi-megawatt PV power systems for commercial rooftops or ground-mount applications.

Aurora Solar / aurorasolar.com

### CPS AMERICA • BOOTH 504

Part of the Shanghai-based Chint Group, an industrial electrical equipment producer, CPS America is a subsidiary of Chint Power Systems, a global inverter supplier for clean energy applications. Founded in Texas, CPS America has been building its inverter business since 2009. The company recently earned the number one market share position in the US for 3-phase string inverters. To support this growing business, CPS America is expanding its US operations. The company has tripled the size CONTINUED ON PAGE 36


**CPS America 1,500 Vdc 125 kW string inverter**

of its original location near Dallas, home to the US service operations, engineering center, analysis laboratory and field technicians. The expanded location now also supports inverter assembly and customer training. The company also has facilities in California, including a fulfillment center in Pomona, as well as a training and support center in Pleasanton. The company's most popular US product line includes 50 kW and 60 kW 3-phase string inverters that provide reactive power support of 55 kVA and 66 kVA, respectively. The company recently announced that these products are compatible with Tigo's flexible module-level power electronics for *NEC 2017* rapid-shutdown compliance. To address the needs of large-scale ground-mount applications, CPS America offers UL-listed 100 kW and 125 kW 1,500 V 3-phase string inverters with a rated output of 600 Vac.

CPS America / 855.584.7168 / chintpowersystems.com

## DYNAPOWER • BOOTH 4145

Since 1963, Vermont-based Dynapower has provided power electronics—such as rectifiers, frequency converters, custom transformers, dc converters and energy storage inverters—to Fortune 500 companies, small enterprises, research institutions and government agencies. The company specializes in designing and building power conversion equipment for challenging applications, including metal finishing, mining, battery formation, chemical production and magnetic silencing for Navy ships. For more than a decade, the Dynapower Energy Storage Group has supplied utility- and commercial-scale power conversion equipment for energy storage applications, such as microgrids, solar-plus-storage, frequency regulation, demand charge reduction and backup power. The company offers not only behind-the-meter and front-of-the-meter energy storage inverters, but also fully integrated energy storage systems complete with lithium-ion batteries. Most recently, Dynapower launched a partner program for traditional central inverter manufacturers that will allow OEM partners to include Dynapower's parallelable 250 kW and 375 kW dc-to-dc converters in their utility-scale offerings.

Dynapower / 877.215.0487 / dynapower.com


**Dynapower 250 kW dc-to-dc converter**

## ENPHASE ENERGY • MULTIPLE BOOTHS

Headquartered in Petaluma, California, Enphase Energy provides software-driven home energy solutions for PV generation, energy storage, and web-based monitoring and control. Way back at SPI 2008, Enphase generated big buzz with the introduction of its first-generation microinverter platform. Since then the company has weathered the ups and downs of life on the solar coaster. Quickly garnering residential market leadership, Enphase completed an IPO in 2012 to become a publicly traded company on NASDAQ. At the time, the company accounted for more than 50% of the US residential market and 72% of the global microinverter market. Peaking in value in late 2014, the stock price fell throughout 2015 and remained low for the better part of 2 years, pressured by falling prices, international competition and eroding market share. Rumors of the company's demise swirled, as many people wondered publicly and privately whether NASDAQ would delist it. In spite of the noise, Enphase continued to improve its microinverter line, develop new products and expand to new markets. Today, guided by a new CEO, the company is in the midst of a remarkable business turnaround. Since late 2017, its stock price has trended up, along with investor confidence. In early 2018, it released its seventh-generation microinverter. In August, the company completed the acquisition of SunPower's microinverter business, eliminating one of its competitors while gaining a potential long-term customer. Enphase will not have its own booth at SPI. However, distribution and module partners, such as AEE Solar (Booth 3420) and LG Electronics (Booth 2638), will undoubtedly showcase Enphase's latest products and innovations.

Enphase IQ 7+ microinverter

Enphase Energy / 877.797.4743 / enphase.com

## ESDEC • BOOTH 378

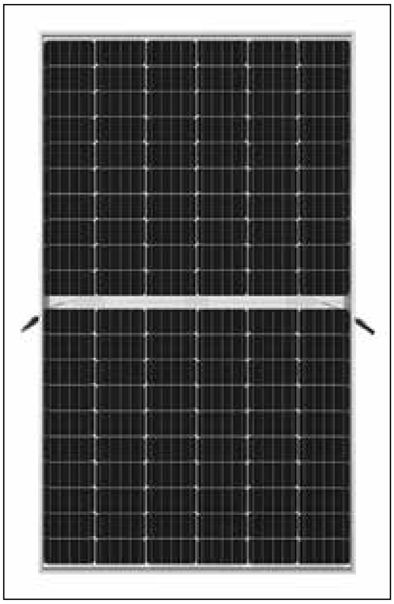
Netherlands-based Esdec is one of the leading rooftop PV mounting companies in Europe, with more than 1.5 GW of systems deployed. Esdec is entering the US market with FlatFix, which features an innovative clickable design architecture for commercial flat roofs of different sizes and membrane materials, as well as a 20-year warranty and full UL certification. A company founded by installers, Esdec designed FlatFix for installers. The mounting system enables rapid assembly, providing commercial installers up to a 40% reduction in installation time compared to other systems on the market. Installers can push-fit the racking components into a locked position without the use of any tools. The rails click together easily and quickly to form an interconnected solid structure. Module installation requires only one tool and a minimum of parts, while optimizers attach easily via snap-on clips. Using self-leveling baseplates, FlatFix is available with both ballast and minimally attached hybrid options and can be deployed in either a traditional south-facing direction or a dual-tilt orientation. FlatFix Fusion's materials and design compensate for thermal effects, reducing potential heat-induced degradation of the PV modules and protecting the integrity of the roof.

Esdec / 800.374.5551 / esdecusa.com


Esdec FlatFix Fusion roof mount

## LONGI SOLAR • BOOTH 528

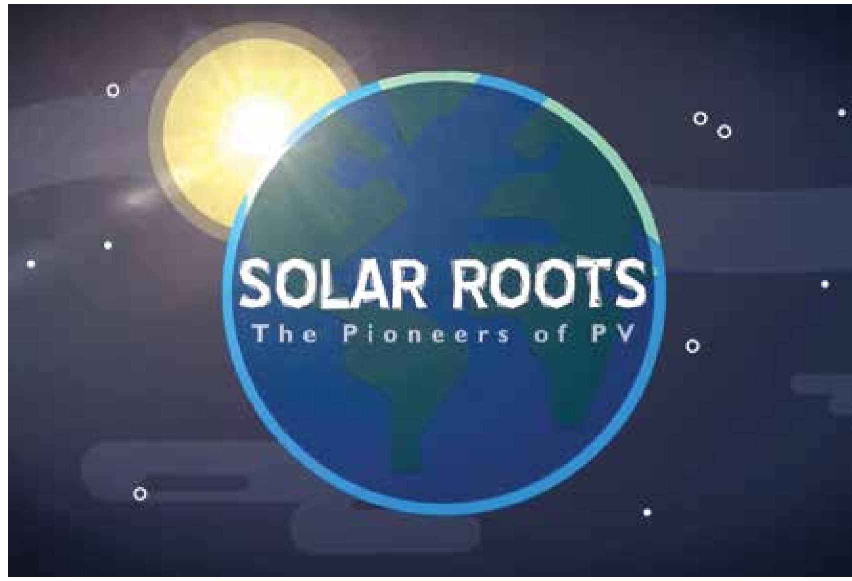
Established in 2000 and headquartered in China, LONGi Solar has experienced rapid growth in recent years and shows no signs of slowing down. The company expanded from 2 GW of monocrystalline silicon (mc-Si) wafer capacity at the end of 2014 to 15 GW at the close of 2017 and could reach 28 GW by December 2018. The company's dizzying goal is to reach 45 GW wafer capacity by 2020. With a strong focus on research and development, LONGi Solar is pushing the limits not only in terms of growth, but also, more importantly, in terms of cell efficiency and module performance. The company's warranty terms are among the best in the industry, with a 10-year equipment warranty and a 30-year, 84.95% output-power warranty, which assumes less than 2% linear power degradation in year 1 and a linear power degradation rate of -0.45% in subsequent years. LONGi Solar holds several performance records, including the world's highest mono PERC module efficiency (20.41%). Its technology road map includes bifacial PERC modules, as well as more efficient bifacial mono PERC modules with half-cut cells.


LONGi Solar half-cut bifacial PERC module

LONGi Solar / en.longi-solar.com

### *SOLAR ROOTS* MOVIE SCREENING • ANAHEIM MARRIOTT

The birth of the terrestrial solar industry was not televised. Instead, a small tribe of backwoods engineers, counterculture technophiles and hippie entrepreneurs pioneered it, far from the city lights and centers of political power. These early adopters, many of whom had a green thumb and an affinity for the Grateful Dead, co-opted and democratized cold war–era space race technology to literally bring power to the people. Realizing that these venerable PV pioneers would not be around forever, Jeff Spies and Jason Vetterli spent 2 years traveling the country and interviewing more than 50 of the men and women who championed solar and gave birth to the home-power movement in the early 1980s. The result is the entertaining and educational documentary film *Solar Roots: The Pioneers of PV.* Aided by solar historian John Perlin, the film breathes life into the chronology of solar electricity, from early scientific discoveries in the 1800s and the Bell Solar Battery in the 1950s to the role of solar in space and its early terrestrial deployments in the 1970s. More poignantly, the film celebrates the colorful trailblazers and intrepid homesteaders who planted and nurtured the seed of the modern solar industry, chronicling their empowering origin story. The filmmakers have posted a 10-minute extended trailer online and will host an advanced




***Solar Roots: The Pioneers of PV* documentary film**

screening at the Anaheim Marriott in one of SPI's conference rooms. This special screening is scheduled for 4:30pm–6:30pm on Wednesday, September 26.

*Solar Roots: The Pioneers of PV* / solar-roots.com

## SOLARBOS • BOOTH 1760

Founded in 2004 and headquartered in Livermore, California, SolarBOS provides a wide variety of electrical balance of system (eBOS) components for the solar industry, including source-circuit combiners, source-circuit wire bundles, disconnect enclosures, overmolded wire harnesses and ac combiners. To provide timely service, the company has more than 65,000 square feet of combined manufacturing space between Livermore and Grand Rapids, Michigan. As commercial- and utility-scale project developers' needs evolve over time based on changing market conditions or new code requirements, SolarBOS responds with products that provide reliable and cost-effective eBOS solutions. At SPI, the company will showcase ac combiner and rack solutions for distributed string inverter clusters or central inverter topologies. It will feature a new line


SolarBOS 1,500 Vdc disconnect combiner


Soltec SF7 Bifacial single-axis tracker

of utility combiners for large-scale ground-mounted systems designed to facilitate quick installation and hassle-free mounting while maintaining the convenience of a combiner box for operations and maintenance. SolarBOS will also display an innovative combiner with higher-current (45 A) inputs, which reduces eBOS costs on sites deployed using three-string rows, a practice common on single-axis tracker projects.

SolarBOS / 925.456.7744 / solarbos.com

## SOLTEC • BOOTH 1450

Founded in 2004 and headquartered in Molina de Segura, Spain, Soltec is a multinational solar tracker manufacturer with facilities in Australia, Asia, Europe, and North and South America, and more than 750 employees worldwide. The company established its US operation in 2015 and recently appointed energy industry veteran Bill Overholt as general manager of its North American subsidiary. Soltec America is headquartered in Livermore, California, which serves as the base for its US sales, logistics and technical support. Soltec's current-generation product line is the SF7 single-axis tracker, designed to provide the highest possible per-acre yield while withstanding extreme climates. The tracker integrates a proprietary fused wire harness that eliminates the need for combiner boxes and serves as a homerun trunk cable, conveniently routed inside the tracker torque tube. This product line includes the SF7 Bifacial, a single-axis tracker optimized for use with newer bifacial PERC modules. The SF7 Bifacial tracker design avoids backside shading by eliminating perpendicular rails and intentionally spreading the gap between modules at the torque tube location. The product is also fielded in a manner that increases diffuse irradiance capture on the backside of bifacial arrays, with double-wide service aisles and an elevated height profile. In July, Soltec America inaugurated the Bifacial Tracker Evaluation Center (BiTEC), also located in Livermore, where it will rigorously assess bifacial tracker performance in comparison to other PV applications, in partnership with bifacial module manufacturers, independent engineering firms and the National Renewable Energy Laboratory.

Soltec / 510.440.9200 / soltec.com

**CONTACT**

David Brearley / *SolarPro* / Ashland, OR /
david.brearley@solarprofessional.com / solarprofessional.com

# 2018 3-Phase String Inverter Spec

| | | Input Data (dc) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Manufacturer | Model | Max. PV power at STC (W) | Max. open-circuit voltage | PV start voltage | Operating voltage range | Number of MPP trackers | MPPT voltage range[1] | Number of dc input circuits | Max. usable input current[2] | Max. short-circuit current[2] |
| ABB | TRIO-20.0-TL-OUTD | DNR | 1,000 | 360[3] | 200–950 | 2 | 450–800 | 2 x 4 | 2 x 25 | 2 x 30 |
| ABB | TRIO-27.6-TL-OUTD | DNR | 1,000 | 360[3] | 200–950 | 2 | 520–800 | 2 x 4 | 2 x 30.9 | 2 x 36 |
| ABB | TRIO-50.0-TL-OUTD-US | DNR | 1,000 | 360[3] | 250–950 | 1 | 520–800 | 1, 12, 16 | 100 | 144 |
| ABB | TRIO-60.0-TL-OUTD-US | DNR | 1,000 | 360[3] | 360–950 | 1 | 570–800 | 1, 12, 16 | 108 | 170 |
| ABB | TRIO-TM-60.0-US-480 | DNR | 1,000 | 360[3] | 360–950 | 3 | 570–800 | 5 x 3 | 3 x 36 | 3 x 55 |
| CPS America | CPS SC14KTL-DO/US-208 | 19,000 | 600 | 300 | 180–580 | 2 | 300–540 | 2 x 4 | 2 x 25 | 2 x 45 |
| CPS America | CPS SC20KTL-DO/US-480 | 27,000 | 600 | 300 | 260–580 | 2 | 300–550 | 2 x 4 | 2 x 35 | 2 x 45.5 |
| CPS America | CPS SCA23KTL-DO/US-480 | 31,000 | 1,000 | 330 | 240–950 | 2 | 480–800 | 2 x 4 | DNR | 2 x 41 |
| CPS America | CPS SCA28KTL-DO/US-480 | 38,000 | 1,000 | 330 | 240–950 | 2 | 500–800 | 2 x 4 | DNR | 2 x 48 |
| CPS America | CPS SCA36KTL-DO/US-480 | 54,000 | 1,000 | 320 | 240–950 | 2 | 540–800 | 2 x 5 | DNR | 2 x 62.5 |
| CPS America | CPS SCA50KTL-DO/US-480 | 75,000 | 1,000 | 330 | 200–950 | 3 | 480–850 | 3 x 5 | DNR | 3 x 68 |
| CPS America | CPS SCA60KTL-DO/US-480 | 90,000 | 1,000 | 330 | 200–950 | 3 | 540–850 | 3 x 5 | DNR | 3 x 60 |
| CPS America | CPS SCH100KTL-DO/US-600 | 150,000 | 1,500 | 900 | 860–1,450 | 1 | 870–1,300 | 16 | DNR | 220 |
| CPS America | CPS SCH125KTL-DO/US-600 | 187,500 | 1,500 | 900 | 860–1,450 | 1 | 870–1,300 | 20 | DNR | 275 |
| Delta | M24U | 34,000 | 1,100 | 250 | 200–1,000 | 2 | 415–830 | 2 x 3 | 2 x 30 | DNR |
| Delta | M28U | 39,000 | 1,100 | 250 | 200–1,000 | 2 | 485–830 | 2 x 3 | 2 x 30 | DNR |
| Delta | M36U | 50,000 | 1,100 | 250 | 200–1,000 | 2 | 520–830 | 2 x 4 | 2 x 36 | DNR |
| Delta | M42U | 60,000 | 1,100 | 250 | 200–1,000 | 2 | 545–830 | 2 x 5 | 2 x 40 | DNR |
| Delta | M60U | 89,000 | 1,100 | 250 | 200–1,000 | 2 | 520–800 | 1, 16, 18[6] | 2 x 60 | 2 x 108 |
| Delta | M80U | 112,000 | 1,100 | 250 | 200–1,000 | 2 | 600–800 | 1, 16, 18[6] | 2 x 70 | 2 x 108 |
| Fronius USA | Symo 10.0-3 208/240 | 13,000 | 600 | 200 | 200–600 | 2 | 300–500 | 6 | 25/16.5[7] | 37.5/24.8[7] |
| Fronius USA | Symo 10.0-3 480 | 15,500 | 600 | 200 | 200–600 | 2 | 300–500 | 6 | 25/16.5[7] | 37.5/24.8[7] |
| Fronius USA | Symo 12.0-3 208/240 | 13,000 | 1,000 | 200 | 200–1,000 | 2 | 300–800 | 6 | 25/16.5[7] | 37.5/24.8[7] |
| Fronius USA | Symo 12.5-3 480 | 16,000 | 1,000 | 200 | 200–1,000 | 2 | 300–800 | 6 | 25/16.5[7] | 37.5/24.8[7] |
| Fronius USA | Symo 15.0-3 280 | 19,500 | 1,000 | 360 | 325–1,000 | 1 | 325–850 | 6 | 50 | 75 |
| Fronius USA | Symo 15.0-3 480 | 19,500 | 1,000 | 200 | 200–1,000 | 2 | 350–800 | 6 | 33/25[7] | 49.5/37.5[7] |
| Fronius USA | Symo 17.5-3 480 | 23,000 | 1,000 | 200 | 200–1,000 | 2 | 400–800 | 6 | 33/25[7] | 49.5/37.5[7] |
| Fronius USA | Symo 20.0-3 480 | 26,000 | 1,000 | 200 | 200–1,000 | 2 | 450–800 | 6 | 33/25[7] | 49.5/37.5[7] |
| Fronius USA | Symo 22.7-3 480 | 9,500 | 1,000 | 200 | 200–1,000 | 2 | 500–800 | 6 | 33/25[7] | 49.5/37.5[7] |
| Fronius USA | Symo 24.0-3 480 | 31,000 | 1,000 | 200 | 200–1,000 | 2 | 500–800 | 6 | 33/25[7] | 49.5/37.5[7] |
| Ginlong Solis | Solis-25K-US | DNR | 1,000 | 350 | 200–800 | 4 | DNR | 4 x 2 | 4 x 18 | DNR |
| Ginlong Solis | Solis-30K-US | DNR | 1,000 | 350 | 200–800 | 4 | DNR | 4 x 2 | 4 x 18 | DNR |
| Ginlong Solis | Solis-36K-US | DNR | 1,000 | 350 | 200–800 | 4 | DNR | 4 x 2 | 4 x 18 | DNR |
| Ginlong Solis | Solis-40K-US | DNR | 1,000 | 350 | 200–800 | 4 | DNR | 4 x 2 | 4 x 18 | DNR |
| Ginlong Solis | Solis-50K-US | DNR | 1,000 | 200 | 200–850 | 4 | DNR | 4 x 3 | 4 x 22 | DNR |
| Ginlong Solis | Solis-60K-US-F | DNR | 1,000 | 200 | 200–850 | 4 | DNR | 4 x 4 | 4 x 28.5 | DNR |
| Ginlong Solis | Solis-66K-US-F | DNR | 1,000 | 200 | 200–850 | 4 | DNR | 4 x 4 | 4 x 28.5 | DNR |
| Growatt USA | 10000TL3-US | DNR | 600 | 120 | 80–600 | 2 | 250–600 | 2 x 3 | 2 x 21 | 2 x 32 |
| Growatt USA | 12000TL3-US | DNR | 600 | 120 | 80–600 | 2 | 250–600 | 2 x 3 | 2 x 25 | 2 x 32 |
| Growatt USA | 18000TL3-US | DNR | 600 | 120 | 80–600 | 2 | 250–600 | 2 x 5 | 2 x 38 | 2 x 50 |
| Growatt USA | 20000TL3-US | DNR | 600 | 120 | 80–600 | 2 | 250–600 | 2 x 5 | 2 x 42 | 2 x 50 |
| Growatt USA | 33000 TL3-US | DNR | 1,000 | 250 | 200–1,000 | 2 | 480–800 | 2 x 4 | 2 x 36 | 2 x 45 |
| Growatt USA | 36000 TL3-US | DNR | 1,000 | 250 | 200–1,000 | 2 | 520–800 | 2 x 4 | 2 x 36 | 2 x 45 |
| Growatt USA | 40000 TL3-US | DNR | 1,000 | 250 | 200–1,000 | 2 | 570–800 | 2 x 4 | 2 x 36 | 2 x 45 |
| HiQ Solar | TrueString TS208-5k75 | DNR | 1,000 | 200 | DNR | 2 | 325–525 | 2 | 2 x 10 | 30 |
| HiQ Solar | TrueString TS480-8k | DNR | 1,000 | 200 | DNR | 2 | 425–850 | 2 | 2 x 10 | 30 |

# cifications

### Footnote Key

[1] Full-power MPPT voltage range
[2] Per MPP tracker
[3] Default, adjustable 250 Vdc–500 Vdc
[4] Wiring boxes available in multiple product variants
[5] Includes integrated wiring box if applicable
[6] Fused string input, terminal block and MC4 connector wiring box options
[7] MPPT 1/MPPT 2
[8] Active fan-cooled option available
[9] Connector approved as load-break disconnect
[10] PV Link S2501 subarray optimizer specification
[11] Nominal dc input voltage
[12] String-level MPP tracking
[13] With SMA Connection Unit 1000-US
[14] Module-level MPP tracking
[15] Primary unit dimension, add two 21-by-12.5-by-10.5-inch secondary units
[16] Primary unit dimension, add one 21-by-12.5-by-10.5-inch secondary units
[17] Total weight, components installed as separate units
DNR = Does not report

| Output Data (ac) | | | Operation | | Disconnects and Combiners | | | Mechanical | | | Contact |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rated power (W) | Nominal output voltage | Rated output current | CEC efficiency (%) | Ambient temp. range (ºF) | DC disconnect | AC disconnect | Fused combiner | Cooling method | Dimensions H x W x D (in.)[5] | Weight (lb.)[5] | Website |
| 20,000 | 480 | 27 | 97.5 | -22–140 | yes[4] | no | yes[4] | passive | 41.7 x 27.6 x 11.5 | 157 | abb.com/solarinverters |
| 27,600 | 480 | 36 | 97.5 | -22–140 | yes[4] | no | yes[4] | passive | 41.7 x 27.6 x 11.5 | 168 | |
| 50,000 | 480 | 61 | 98 | -13–140 | yes[4] | yes[4] | option[4] | active | 28.5 x 58.7 x 12.4 | 209 | |
| 60,000 | 480 | 77 | 98 | -13–140 | yes[4] | yes[4] | option[4] | active | 28.5 x 58.7 x 12.4 | 210 | |
| 60,000 | 480 | 77 | 98 | -13–140 | yes[4] | yes[4] | yes[4] | active | 28.5 x 58.7 x 12.4 | 210 | |
| 14,000 | 208 | 39 | 96 | -13–140 | yes | yes | yes | active | 41.6 x 21.4 x 8.5 | 141 | chintpowersystems.com |
| 20,000 | 480 | 24 | 97 | -13–140 | yes | yes | yes | active | 41.6 x 21.4 x 8.5 | 141 | |
| 23,000 | 480 | 27.7 | 98 | -22–140 | yes | yes | yes | active | 39.4 x 23.6 x 9.1 | 124 | |
| 28,000 | 480 | 33.7 | 98 | -22–140 | yes | yes | yes | active | 39.4 x 23.6 x 9.1 | 124 | |
| 36,000 | 480 | 43.5 | 98 | -22–140 | yes | yes | yes | active | 39.4 x 23.6 x 9.1 | 145 | |
| 50,000 | 480 | 60.2 | 98.5 | -22–140 | yes | yes | yes | active | 39.4 x 23.6 x 10.2 | 157 | |
| 60,000 | 480 | 72.2 | 98.5 | -22–140 | yes | yes | yes | active | 39.4 x 23.6 x 10.2 | 157 | |
| 100,000 | 600 | 106.9 | 98.5 | -22–140 | yes | yes | yes | active | 24.3 x 45.3 x 9.8 | 176 | |
| 125,000 | 600 | 127.2 | 98.5 | -22–140 | yes | yes | yes | active | 24.3 x 45.3 x 9.8 | 176 | |
| 24,000 | 277/480 | 32.1 | 98 | -13–140 | yes | yes | yes | active | 32.3 x 24.2 x 11 | 127 | delta-americas.com |
| 28,000 | 277/480 | 37.5 | 98 | -13–140 | yes | yes | yes | active | 32.3 x 24.2 x 11 | 127 | |
| 36,000 | 277/480 | 48.2 | 98 | -13–140 | yes | yes | yes | active | 32.3 x 24.2 x 11 | 129 | |
| 42,000 | 277/480 | 56.2 | 98 | -13–140 | yes | yes | yes | active | 32.3 x 24.2 x 11 | 131 | |
| 60,000 | 277/480 | 80 | 98.5 | -13–140 | yes | yes | yes[6] | active | 35.4 x 24.2 x 10.8 | 181 | |
| 80,000 | 277/480 | 100 | 98.5 | -13–140 | yes | yes | yes[6] | active | 35.4 x 24.2 x 10.8 | 181 | |
| 9,995 | 208/240 | 27.7/24 | 96.5 | -40–140 | yes | no | no | active | 28.5 x 20.1 x 8.9 | 92 | fronius-usa.com |
| 11,995 | 208/240 | 33.3/28.9 | 96.5 | -40–140 | yes | no | no | active | 28.5 x 20.1 x 8.9 | 92 | |
| 9,995 | 480 | 12 | 96.5 | -40–140 | yes | no | no | active | 28.5 x 20.1 x 8.9 | 77 | |
| 12,495 | 480 | 15 | 97 | -40–140 | yes | no | no | active | 28.5 x 20.1 x 8.9 | 77 | |
| 15,000 | 208 | 41.6 | 96.5 | -40–140 | yes | no | yes | active | 28.5 x 20.1 x 8.9 | 78 | |
| 14,995 | 480 | 18 | 97 | -40–140 | yes | no | no | active | 28.5 x 20.1 x 8.9 | 96 | |
| 17,495 | 480 | 21 | 97.5 | -40–140 | yes | no | no | active | 28.5 x 20.1 x 8.9 | 96 | |
| 19,995 | 480 | 24 | 97.5 | -40–140 | yes | no | yes | active | 28.5 x 20.1 x 8.9 | 96 | |
| 22,727 | 480 | 27.3 | 97.5 | -40–140 | yes | no | yes | active | 28.5 x 20.1 x 8.9 | 96 | |
| 23,995 | 480 | 28.9 | 97.5 | -40–140 | yes | no | yes | active | 28.5 x 20.1 x 8.9 | 96 | |
| 25,000 | 480 | 30.1 | 98.3 | -13–140 | yes | no | no | passive | 37.2 x 23.4 x 14.4 | 148 | ginlong.com |
| 30,000 | 480 | 36.1 | 98.3 | -13–140 | yes | no | no | passive | 37.2 x 23.4 x 14.4 | 148 | |
| 36,000 | 480 | 43.3 | 98.3 | -13–140 | yes | no | no | passive[8] | 38 x 21.1 x 14.4 | 177 | |
| 40,000 | 480 | 48.1 | 98.3 | -13–140 | yes | no | no | passive[8] | 38 x 21.1 x 14.4 | 177 | |
| 50,000 | 480 | 60.2 | 98.4 | -13–140 | yes | no | DNR | passive[8] | 40.7 x 24.8 x 13.9 | 165 | |
| 60,000 | 480 | 72.2 | 98.4 | -13–140 | yes | no | DNR | active | 40.7 x 24.8 x 13.9 | 172 | |
| 66,000 | 480 | 79.4 | 98.4 | -13–140 | yes | no | DNR | active | 40.7 x 24.8 x 13.9 | 172 | |
| 10,000 | 480 | 12 | 95.5 | -13–140 | yes | no | no | active | 27.7 x 20.9 x 9.7 | 101 | growatt-america.com |
| 12,000 | 480 | 14.5 | 95.5 | -13–140 | yes | no | no | active | 27.7 x 20.9 x 9.7 | 101 | |
| 18,000 | 480 | 21.5 | 96 | -13–140 | yes | no | no | active | 29.1 x 25.6 x 9.7 | 139 | |
| 20,000 | 480 | 24 | 96 | -13–140 | yes | no | no | active | 29.1 x 25.6 x 9.7 | 139 | |
| 33,000 | 480 | 44 | 98.5 | -13–140 | yes | yes | yes | active | 31.1 x 17.3 x 10.8 | 110 | |
| 36,000 | 480 | 44 | 98.5 | -13–140 | yes | yes | yes | active | 31.1 x 17.3 x 10.8 | 110 | |
| 40,000 | 480 | 48 | 98.5 | -13–140 | yes | yes | yes | active | 31.1 x 17.3 x 10.8 | 110 | |
| 5,750 | 208 | 16 | 97 | -40–150 | yes[9] | yes[9] | no | passive | 18.7 x 13.2 x 3 | 24 | hiqsolar.com |
| 8,000 | 480 | 9.6 | 98 | -40–150 | yes[9] | yes[9] | no | passive | 18.7 x 13.2 x 3 | 24 | |

# 2018 3-Phase String Inverter Specifications

| | | Input Data (dc) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Manufacturer | Model | Max. PV power at STC (W) | Max. open-circuit voltage | PV start voltage | Operating voltage range | Number of MPP trackers | MPPT voltage range[1] | Number of dc input circuits | Max. usable input current[2] | Max. short-circuit current[2] |
| Huawei | SUN2000-25KTL-US | DNR | 1,000 | 250 | 250–950 | 3 | DNR | 3 x 2 | 3 x 25 | 3 x 33 |
| Huawei | SUN2000-30KTL-US | DNR | 1,000 | 250 | 250–950 | 3 | DNR | 3 x 2 | 3 x 25 | 3 x 33 |
| Huawei | SUN2000-33KTL-US | DNR | 1,000 | 250 | 200–1,000 | 4 | DNR | 4 x 2 | 4 x 22 | 4 x 30 |
| Huawei | SUN2000-36KTL-US | DNR | 1,000 | 250 | 200–1,000 | 4 | DNR | 4 x 2 | 4 x 22 | 4 x 30 |
| Huawei | SUN2000-40KTL-US | DNR | 1,000 | 250 | 200–1,000 | 4 | DNR | 4 x 2 | 4 x 22 | 4 x 30 |
| Huawei | SUN2000-45KTL-US-HV-D0 | DNR | 1,500 | 650 | 600–1,450 | 4 | DNR | 4 x 2 | 4 x 22 | 4 x 30 |
| Huawei | SUN2000-100KTL-USH0 | DNR | 1,500 | 650 | 600–1,500 | 6 | 800–1,300 | 6 x 2 | 6 x 22 | 6 x 40 |
| KACO new energy | blueplanet 125 TL3 | 187,500 | 1,500 | 975 | 875–1,450 | 1 | 875–1,300 | 1 | 150 | 300 |
| Pika Energy | X11402 | DNR | 420[10] | 60[10] | 380[11] | varies[12] | 60–360 [10] | varies[12] | 30 | DNR |
| REFUsol | 24K-UL | DNR | 1,000 | 200 | 200–950 | 1 | 570–890 | 1 | 44 | 80 |
| REFUsol | 48K-UL | DNR | 1,000 | 200 | 200–950 | 1 | 580–850 | 1 | 84 | 160 |
| Schneider Electric | CL-60A | DNR | 1,000 | 620 | 550–950 | 1 | 550–850 | 14 | 120 | 140 |
| Schneider Electric | CL-125A | DNR | 1,500 | 920 | 860–1,450 | 1 | 860–1,250 | 1 | 148 | 240 |
| SMA America | STP 12000TL-US | 18,000 | 1,000 | 188 | 150–1,000 | 2 | 300–800 | 4 x 2[13] | 2 x 33 | 2 x 53 |
| SMA America | STP 15000TL-US | 22,500 | 1,000 | 188 | 150–1,000 | 2 | 300–800 | 4 x 2[13] | 2 x 33 | 2 x 53 |
| SMA America | STP 20000TL-US | 30,000 | 1,000 | 188 | 150–1,000 | 2 | 300–800 | 4 x 2[13] | 2 x 33 | 2 x 53 |
| SMA America | STP 24000TL-US | 36,000 | 1,000 | 188 | 150–1,000 | 2 | 450–800 | 4 x 2[13] | 2 x 33 | 2 x 53 |
| SMA America | STP 30000TL-US | 45,000 | 1,000 | 188 | 150–1,000 | 2 | 500–800 | 4 x 2[13] | 2 x 33 | 2 x 53 |
| SMA America | STP CORE1 33-US | 50,000 | 1,000 | 188 | 150–1,000 | 6 | 330–800 | 6 x 2 | 6 x 20 | 6 x 30 |
| SMA America | STP CORE1 50-US | 75,000 | 1,000 | 188 | 150–1,000 | 6 | 500–800 | 6 x 2 | 6 x 20 | 6 x 30 |
| SMA America | STP CORE1 62-US | 93,750 | 1,000 | 188 | 150–1,000 | 6 | 550–800 | 6 x 2 | 6 x 20 | 6 x 30 |
| SolarEdge Technologies | SE9KUS | 12,150 | 500 | varies[14] | 400[11] | varies[14] | varies [14] | 2 | 26.5 | 45 |
| SolarEdge Technologies | SE10KUS | 13,500 | 980 | varies[14] | 840[11] | varies[14] | varies [14] | 2 | 13.5 | 45 |
| SolarEdge Technologies | SE14.4KUS | 19,400 | 600 | varies[14] | 400[11] | varies[14] | varies [14] | 3 | 38 | 45 |
| SolarEdge Technologies | SE20KUS | 27,000 | 980 | varies[14] | 840[11] | varies[14] | varies [14] | 2 | 26.5 | 45 |
| SolarEdge Technologies | SE30KUS | 40,500 | 980 | varies[14] | 840[11] | varies[14] | varies [14] | 3 | 39 | 45 |
| SolarEdge Technologies | SE33.3KUS | 45,000 | 980 | varies[14] | 840[11] | varies[14] | varies [14] | 3 | 40 | 45 |
| SolarEdge Technologies | SE43.2KUS | 58,200 | 600 | varies[14] | 400[11] | varies[14] | varies [14] | 3 | 114 | 135 |
| SolarEdge Technologies | SE66.6KUS | 90,000 | 1,000 | varies[14] | 850[11] | varies[14] | varies [14] | 3 | 80 | 120 |
| SolarEdge Technologies | SE100KUS | 135,000 | 1,000 | varies[14] | 850[11] | varies[14] | varies [14] | 3 | 120 | 120 |
| Sungrow USA | SG125HV | DNR | 1,500 | 920 | 860–1,450 | 1 | 860–1,250 | 1 | 148 | 240 |
| Yaskawa–Solectria Solar | PVI 14TL | 19,000 | 600 | 300 | 180–580 | 2 | 300–540 | 2 x 4 | 2 x 25 | 2 x 45 |
| Yaskawa–Solectria Solar | PVI 20TL | 27,000 | 600 | 300 | 260–580 | 2 | 300–550 | 2 x 4 | 2 x 35 | 2 x 45.5 |
| Yaskawa–Solectria Solar | PVI 23TL | 31,000 | 1,000 | 330 | 240–950 | 2 | 480–800 | 2 x 4 | 2 x 25 | 2 x 41 |
| Yaskawa–Solectria Solar | PVI 28TL | 38,000 | 1,000 | 330 | 240–950 | 2 | 500–800 | 2 x 4 | 2 x 29 | 2 x 48 |
| Yaskawa–Solectria Solar | PVI 36TL | 54,000 | 1,000 | 330 | 240–950 | 2 | 540–800 | 2 x 5 | 2 x 35 | 2 x 62.5 |
| Yaskawa–Solectria Solar | PVI 50TL | 75,000 | 1,000 | 330 | 200–950 | 3 | 480–850 | 3 x 5 | 3 x 36 | 3 x 60 |
| Yaskawa–Solectria Solar | PVI 60TL | 90,000 | 1,000 | 330 | 200–950 | 3 | 540–850 | 3 x 5 | 3 x 38 | 3 x 60 |
| Yaskawa–Solectria Solar | XGI 1000-50/60 | 75,000 | 1,000 | DNR | 350–950 | 4 | 580–850 | 4 x 4 | 4 x 22 | 180 |
| Yaskawa–Solectria Solar | XGI 1000-60/60 | 90,000 | 1,000 | DNR | 350–950 | 4 | 580–850 | 4 x 4 | 4 x 26.4 | 180 |
| Yaskawa–Solectria Solar | XGI 1000-60/65 | 90,000 | 1,000 | DNR | 350–950 | 4 | 600–850 | 4 x 4 | 4 x 26.4 | 180 |
| Yaskawa–Solectria Solar | XGI 1000-65/65 | 97,600 | 1,000 | DNR | 350–950 | 4 | 600–850 | 4 x 4 | 4 x 27.7 | 180 |

**Footnote Key**

[1] Full-power MPPT voltage range
[2] Per MPP tracker
[3] Default, adjustable 250 Vdc–500 Vdc
[4] Wiring boxes available in multiple product variants
[5] Includes integrated wiring box if applicable
[6] Fused string input, terminal block and MC4 connector wiring box options
[7] MPPT 1/MPPT 2
[8] Active fan-cooled option available
[9] Connector approved as load-break disconnect
[10] PV Link S2501 subarray optimizer specification
[11] Nominal dc input voltage
[12] String-level MPP tracking
[13] With SMA Connection Unit 1000-US
[14] Module-level MPP tracking
[15] Primary unit dimension, add two 21-by-12.5-by-10.5-inch secondary units
[16] Primary unit dimension, add one 21-by-12.5-by-10.5-inch secondary units
[17] Total weight, components installed as separate units
DNR = Does not report

| Output Data (ac) | | | Operation | | Disconnects and Combiners | | | Mechanical | | | Contact |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rated power (W) | Nominal output voltage | Rated output current | CEC efficiency (%) | Ambient temp. range (ºF) | DC disconnect | AC disconnect | Fused combiner | Cooling method | Dimensions H x W x D (in.)[5] | Weight (lb.)[5] | Website |
| 25,000 | 480 | 33 | 98 | -13–140 | yes | no | no | passive | 30.3 x 21.7 x 11.1 | 126 | solar.huawei.com |
| 30,000 | 480 | 40 | 98 | -13–140 | yes | no | no | passive | 30.3 x 21.7 x 11.1 | 126 | |
| 33,300 | 480 | 40.1 | 98.5 | -13–140 | yes | no | no | passive | 21.7 x 36.6 x 11.1 | 137 | |
| 36,000 | 480 | 43.4 | 98.5 | -13–140 | yes | no | no | passive | 21.7 x 36.6 x 11.1 | 137 | |
| 40,000 | 480 | 48.2 | 98.5 | -13–140 | yes | no | no | passive | 21.7 x 36.6 x 11.1 | 137 | |
| 45,000 | 600 | 48 | 98.5 | -13–140 | yes | no | no | passive | 23.6 x 36.6 x 10.6 | 141 | |
| 100,000 | 800 | 72.9 | 98.5 | -13–140 | yes | no | no | passive | 23.6 x 42.3 x 12.2 | 170 | |
| 125,000 | 600 | 120.3 | 98.5 | -13–140 | no | no | no | active | 27.6 x 27.6 x 17.7 | 160 | kaco-newenergy.com |
| 11,400 | 208 | 32 | 97.5 | -4–122 | yes | no | yes | active | 24.5 x 19.25 x 8 | 63 | pika-energy.com |
| 24,000 | 480 | 29 | 98 | -13–140 | yes | no | no | passive | 24 x 21 x 11 | 88 | refu-sol.com |
| 48,000 | 480 | 59 | 98 | -13–140 | yes | no | no | passive | 32 x 30 x 12 | 163 | |
| 63,400 | 380 | 96 | 98 | -13–140 | yes | yes | yes | active | 38.9 x 25.7 x 9.8 | 147 | schneider-electric.us |
| 125,000 | 600 | 120 | 98.5 | -13–140 | yes | yes | no | active | 26.4 x 35.1 x 11.6 | 165 | |
| 12,000 | 480 | 14.4 | 97.5 | -13–140 | option[13] | no | option[13] | active | 25.6 x 26.2 x 10.4 | 121 | sma-america.com |
| 15,000 | 480 | 18 | 97.5 | -13–140 | option[13] | no | option[13] | active | 25.6 x 26.2 x 10.4 | 121 | |
| 20,000 | 480 | 24 | 97.5 | -13–140 | option[13] | no | option[13] | active | 25.6 x 26.2 x 10.4 | 121 | |
| 24,000 | 480 | 29 | 98 | -13–140 | option[13] | no | option[13] | active | 25.6 x 26.2 x 10.4 | 121 | |
| 30,000 | 480 | 36.2 | 98 | -13–140 | option[13] | no | option[13] | active | 25.6 x 26.2 x 10.4 | 121 | |
| 33,300 | 480 | 40 | 97.5 | -13–140 | yes | yes | no | active | 28.8 x 24.4 x 22.4 | 185 | |
| 50,000 | 480 | 64 | 98 | -13–140 | yes | yes | no | active | 28.8 x 24.4 x 22.4 | 185 | |
| 62,500 | 480 | 79.5 | 98 | -13–140 | yes | yes | no | active | 28.8 x 24.4 x 22.4 | 185 | |
| 9,000 | 208 | 25 | 96.5 | -40–140 | yes | yes | no | active | 30.5 x 12.5 x 10.5 | 80 | solaredge.us |
| 10,000 | 480 | 12 | 98 | -40–140 | yes | yes | no | active | 30.5 x 12.5 x 10.5 | 80 | |
| 14,400 | 208 | 40 | 97 | -40–140 | yes | yes | option | active | 30.5 x 12.5 x 10.5 | 106 | |
| 20,000 | 480 | 24 | 98 | -40–140 | yes | yes | no | active | 30.5 x 12.5 x 10.5 | 80 | |
| 30,000 | 480 | 36.5 | 98.5 | -40–140 | yes | yes | option | active | 30.5 x 12.5 x 10.5 | 106 | |
| 33,300 | 480 | 40 | 98.5 | -40–140 | yes | yes | option | active | 30.5 x 12.5 x 10.5 | 106 | |
| 43,200 | 208 | 120 | 97 | -40–140 | yes | no | option | active | 37 x 12.5 x 10.5[15] | 403[17] | |
| 66,600 | 480 | 80 | 98.5 | -40–140 | yes | no | option | active | 37 x 12.5 x 10.5[16] | 304[17] | |
| 100,000 | 480 | 120 | 98.5 | -40–140 | yes | no | option | active | 37 x 12.5 x 10.5[15] | 403[17] | |
| 125,000 | 600 | 120 | 98.5 | -13–140 | yes | yes | no | active | 35.5 x 26.4 x 11.7 | 167.5 | en.sungrowpower.com |
| 14,000 | 208 | 39 | 96 | -13–140 | yes | yes | yes | active | 41.6 x 21.4 x 8.5 | 141 | solectria.com |
| 20,000 | 480 | 24 | 97 | -13–140 | yes | yes | yes | active | 41.6 x 21.4 x 8.5 | 132 | |
| 23,000 | 480 | 27.7 | 98 | -22–140 | yes | yes | yes | active | 39.4 x 23.6 x 9.1 | 104 | |
| 28,000 | 480 | 33.7 | 98 | -22–140 | yes | yes | yes | active | 39.4 x 23.6 x 9.1 | 104 | |
| 36,000 | 480 | 43.5 | 98 | -22–140 | yes | yes | yes | active | 39.4 x 23.6 x 9.1 | 121 | |
| 50,000 | 480 | 66.2 | 98.5 | -22–140 | yes | yes | yes | active | 39.4 x 23.6 x 10.2 | 157 | |
| 60,000 | 480 | 79.4 | 98.5 | -22–140 | yes | yes | yes | active | 39.4 x 23.6 x 10.2 | 157 | |
| 50,000 | 480 | 72.2 | 98 | -40–140 | yes | no | yes | active | 45.8 x 28.3 x 11.6 | 166 | |
| 60,000 | 480 | 72.2 | 98 | -40–140 | yes | no | yes | active | 45.8 x 28.3 x 11.6 | 166 | |
| 60,000 | 480 | 78.2 | 98 | -40–140 | yes | no | yes | active | 45.8 x 28.3 x 11.6 | 166 | |
| 65,000 | 480 | 78.2 | 98 | -40–140 | yes | no | yes | active | 45.8 x 28.3 x 11.6 | 166 | |

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# Projects
System Profiles

## Borrego Solar

### Sacramento International Airport

Courtesy Borrego Solar (2)

### Overview

**DESIGN:** Torsten Christian, development design engineer, Borrego Solar, borregosolar.com; Benjamin Walter, electrical engineer, Borrego Solar; David Dutil, structural engineer, Borrego Solar; Tarn Yates, applications engineer, Borrego Solar

**INSTALLATION:** Nick Clemens, project manager, Borrego Solar; Darin Flick, field operations manager, Borrego Solar

**DATE COMMISSIONED:** December 2017

**INSTALLATION TIME FRAME:** 245 days

**LOCATION:** Sacramento, CA, 38.7°N

**SOLAR RESOURCE:** 5.04 kWh/m$^2$/day

**ASHRAE DESIGN TEMPERATURES:** 98.6°F 2% average high, 26.6°F extreme minimum

**ARRAY CAPACITY:** 7.9 MWdc

**ANNUAL AC PRODUCTION:** 5,900,000 kWh

The 7.9 MW Sacramento International Airport solar project is the largest on-airport solar facility in California. Commissioned in December 2017, the installation consists of a 15-acre east site on the airport's Aviation Drive and a 20-acre north site located near the runway. Between the two sites, Borrego Solar installed more than 23,000 LG solar modules mounted on NEXTracker self-powered independent-row trackers. The arrays will provide enough energy to offset a projected 30% of the airport's electricity demand, enough to power 1,600 homes annually.

The airport took advantage of a PPA mechanism with NRG Energy, which enabled the airport to deploy solar without any capital outlay. Under this financial structure, NRG owns and operates the facility and sells electricity to Sacramento International Airport at a reduced rate.

# PROJECTS

Courtesy Borrego Solar (2)

The airport pays for the PPA through savings from electricity costs. Projected cost savings from the project are an average of $850,000 annually throughout the 25-year PPA term.

Regulatory requirements for public airports across the country are unique and can pose significant challenges for solar power plant developers. To comply with California Environmental Quality Act requirements, Borrego conducted an owl survey on the north site, and it followed the requirements of the National Environmental Policy Act since this is a federal project. Additionally, the Federal Aviation Administration requires the performance of glare studies for any type of solar project at or in close proximity to an airport, as well as updates to these studies throughout the project life cycle if there are any design changes.

NEXTracker's support team provided Borrego Solar with specialized design, project engineering and on-site tracker installation and O&M training. Asphalt on the 15-acre east site and irregular soft soil on the 20-acre north site complicated project development. NEXTracker assisted Borrego's installation team in driving shortened piers on the east site, where 3 inches of asphalt blanketed the area. The project team installed 13,281 modules on the north site and 9,956 modules on the east site. The typical design configuration deploys 76 modules per independent tracker row.

The airport's electrical infrastructure is a customer-owned campus electricity loop, typical for large-load customers such as airports, colleges and some corporate campuses. Integrating the solar project's five SMA central inverters into the system required two independent medium-voltage connections using three Eaton Cooper Power distribution transformers (two on the north site and one on the east site) to step up the aggregated inverter outputs for medium-voltage transmission.

"The Sacramento airport installation was a major success despite complexities associated with a project of this scope and navigating the security intricacies of constructing at an airport. Our success was due to comprehensive planning and implementation of Borrego core principles in regard to design, installation and logistics. Working through the interconnection process with SMUD was a fantastic experience, due to daily communication and even a gear inspection via video-conference from the Eaton factory. I was extremely impressed by SMUD's ability to keep to a tight timeline that was necessary for the PPA owner."

*—Nick Clemens, Borrego Solar*

## Equipment Specifications

**MODULES:** 23,237 LG Electronics LG340S2W-G4, 340 W STC, +3/-0%, 9.02 Imp, 37.7 Vmp, 9.54 Isc, 46.4 Voc

**INVERTERS:** Three SMA SC800CP-US, 800 kW–rated output, 1,000 Vdc maximum input, 570 Vdc–820 Vdc MPPT range; two SMA SC2200-US, 2,200 kW–rated output, 1,000 Vdc maximum input, 570 Vdc–950 Vdc MPPT range

**ARRAY:** 19 modules per source circuit (6,460 W, 9.02 Imp, 716.3 Vmp, 9.54 Isc, 881.6 Voc), 20 source circuits per combiner (129.2 kW, 180.4 Imp, 716.3 Vmp, 190.8 Isc, 881.6 Voc), 7.9 MWdc array total

**ARRAY INSTALLATION:** NEXTracker NX Horizon single-axis trackers, self-powered independent-row design, 120° (±60°) tracking range, 180° array azimuth

**ARRAY SOURCE CIRCUIT COMBINERS:** 63 SolarBOS CSK320-20-15-N4, 15 A fuses

**ARRAY RECOMBINERS:** Three SolarBOS BEK-09-400-N3, 300 A breakers

**SYSTEM MONITORING:** Locus Energy LGate data acquisition platform