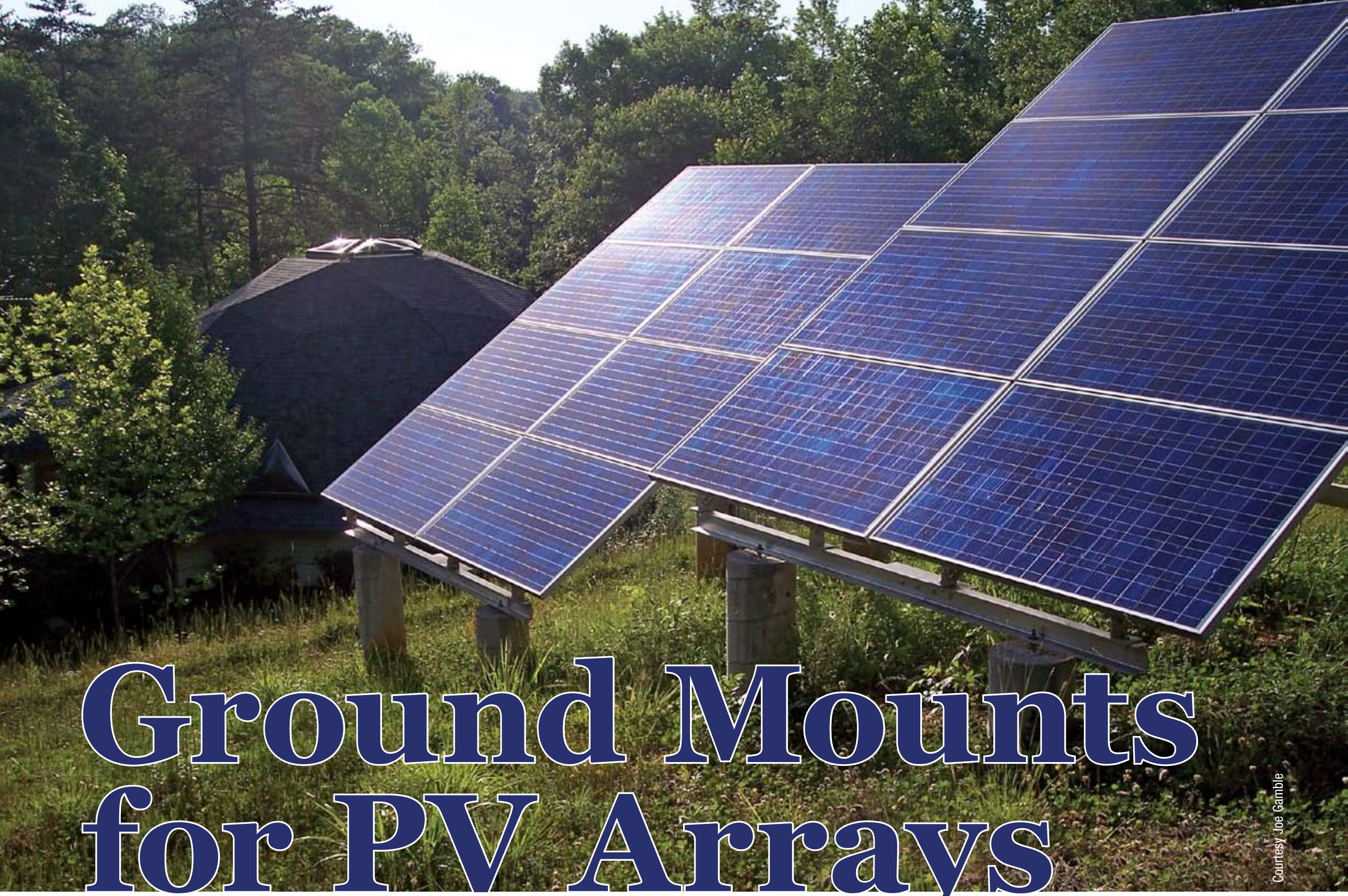


Courtesy Joe Gamble

Ground Mounts for PV Arrays

by Rebekah Hren

Roofs aren't the only places for PV systems—ground-mounted systems offer their own unique advantages.

Choosing the structure to secure your PV array—roof, pole, or ground mount—is a process of weighing the pros and cons of each. Cost or energy-production comparisons might yield an answer, but sometimes the site speaks loud and clear.

Ground mounts, like pole mounts, can often accommodate larger PV arrays, as they are not limited to the size of the roof and can take advantage of the best solar window a site offers. Array installation and maintenance is done on terra firma—no climbing, no safety roping. There are no roof penetrations to leak, and with increased airflow around them, modules can operate at lower temperatures—yielding higher performance. Being able to choose the perfect tilt angle and azimuth also results in optimum performance. And while PV arrays don't *have* to be cleaned, spotless modules do produce more energy; ground-mounted modules can be more easily washed of dirt, dust, and bird droppings. So if a site has wide-open, unshaded space to use for a PV array, ground-mounting can be the best option.

Courtesy Honey Electric Solar

Above: Ground mounts can work in situations where roof mounts won't.

Right: Working from ground level, rather than on a roof, is often safer and easier.

Schletter racks are typically used for large, utility-scale ground-mounted installations.

Rack Details

Ground-mount racks are made of a mix of aluminum and steel poles, rails, and channel attached to ground-anchoring structures—working together to provide the strength to resist live loads (like wind and snow that exert variable uplift and downward pressure) and dead loads (the weight of the rack and modules). While it's possible to scratch-build a ground-mount, it is rarely advisable. The engineering and testing that go into manufacturers' designs take the guesswork out of ground-mounting a PV array, and the end result is likely to be

Zilla racks can use their Helical system, avoiding the use of concrete pier footings.

Engineering Variables

The information that a custom ground-mount manufacturer will need includes:

- **Maximum design wind speed.** This is the highest wind gust speed probable in 50 years, averaged over a 3-second gust at a height of 33 feet. Because wind speeds vary (they are generally higher close to the coast and at high elevations), this is critical information for an engineer. Maximum design wind speeds can be found in the American Society of Civil Engineers (ASCE) Standard 7-10, "Minimum Design Loads for Buildings and Other Structures." However, your local building authority can provide the wind design speeds they require.
- **Snow load.** Measured in pounds per square foot, the weight of snow on a structure can stack up, depending on your location. Snow can be five to more than 15 times heavier than a PV module, and the rack must hold the additional weight. ASCE Standard 7-10 includes common snow-load values, but your local building authority will provide their requirements.
- **Exposure category.** This is related to wind loading and takes into account the turbulence at the site due to surrounding objects (trees, buildings, etc.). There are three main ASCE categories that relate to ground mounts: Category B (lower wind loading)—dense urban and suburban area; Category C (medium wind loading)—open terrain with occasional obstructions; Category D (higher wind loading)—flat and unobstructed terrain. (Category A refers to "large city centers" with at least 50% of the buildings with heights more than 20 meters.)
- **Site slope.** Again, the engineer will be concerned with the physical dimensions of the rack and the maximum slope the racking can accommodate. You'll need to provide the average slope and slope direction.
- **Soil class.** This is necessary for determining specifics for anchors, which behave differently in different soils. Soil classifications are derived from Table 1804.2 of the *International Building Code,* which classifies five general soil types—type 1: crystalline bedrock; type 2: sedimentary and foliated rock; type 3: sandy gravel and/or gravel; type 4: sand, silt, or clay sand, silty gravel, and clayey gravel; and type 5: clay, sandy clay, silty clay, clayey silt, silt, and sandy silt. If there is a mix of soil types, pick the dominant type. The USDA Natural Resources Conservation Service publishes soil surveys which contain maps and a description of each major soil in the survey area. Your local cooperative extension agent can provide you with maps and help determine your soil type. See www.csrees.usda.gov/Extension/ to find your local office.
- **Module type and quantity.** Acquire a specification sheet for your modules for the rack manufacturer, who will need at minimum the number of modules, plus module depth, height, width, and hole layout, to size the rack correctly.
- **Desired tilt angle.** This will be based on your location's latitude and the seasonal variation in solar gain (see "Specifics to Consider" for more details).
- **Ground clearance.** This is the height to the lower edge of the first row of modules (2 feet is typical). This basic design decision should be based on site conditions: potential snow accumulation, ground covering, aesthetics, etc.
- **Number of modules in a string.** This information can help the rack manufacturer design an efficient layout, with strings contained within a row or subarray for less trenching and conduit.

cheaper, sturdier, longer-lasting, better engineered, and quicker to install than a homemade rack.

Ground-mount manufacturers offer versatile designs for PV arrays, from two modules to upwards of 2,000 modules. The manufacturer typically provides a site-specific engineered design, layout, and prefabricated components, along with a list of what needs to be provided locally. The locally sourced parts will vary according to design—some systems come so complete that only concrete needs to be locally sourced. Although some rack manufacturers focus only on larger arrays (20 kW and up), nearly a dozen manufacturers provide smaller array (500 W to 20 kW) solutions, delivering fully engineered mounts with 10- to 15-year warranties.

Courtesy Next Generation Energy

In areas with no vegetative growth or snow shed, racks can attach to concrete at ground level.

Ground-mounted PV modules are arranged in one or more rows, in either a landscape or portrait configuration. A common layout for larger arrays is two rows of modules in a portrait configuration, but smaller array layouts vary substantially, depending on the number of modules. Care should be taken when specifying a design to match the number of modules and series strings with the layout to ensure a symmetrical final product with the shortest possible cable and conduit routes.

Securing the Rack to the Ground

A variety of methods are used to anchor the rack to the ground: poured footings made with concrete column forms; driven steel piles of beam or pipe (or, rarely, wood); "earth screws" (also called "anchors" or "helical piers") and even ballast (see "Ballast Mounts" sidebar).

Most smaller ground-mounted arrays use concrete footings because no special equipment (like a pile driver) is necessary. As more manufacturers join the industry and R&D accelerates, ground-mount anchor installation options are expanding. For example, Next Generation Energy's Helical System uses hot roll steel plate and steel tubing to make a sturdy anchor that quickly "drills" into the soil. The anchors cannot be used in hardpan soils or soils with larger than 6-inch rocks. The depth, diameter, height, and spacing of the ground-mount support anchors, as well as the design of the rack itself, will be specified by the rack manufacturer on a site-by-site basis. The manufacturers engineer the design to the most conservative building code standards for the site specifics, so you must provide accurate inputs for the engineer, or the rack design might not be built to withstand the particular environmental conditions of the site, with potentially catastrophic consequences.

Ground-Mount Planning Checklist

Preliminary

- ☐ **Siting:** Review property lines, shading, setbacks, right-of-ways, or easements; and check for underground utilities.
- ☐ **Civil engineering:** Will grading, storm water runoff mitigation, or environmental reviews be needed? Check with local permitting, planning, and inspection agencies.
- ☐ **Site access:** Is the site accessible to heavy construction machinery if needed?
- ☐ **Accessibility:** Will the array need fencing for security from theft and/or animals, and to comply with *NEC* 690.31A? Be sure there is sufficient space so the fence will not shade the array.

Design

- ☐ **Site-specific info:** Catalog wind speed, snow loads, soil conditions, etc.
- ☐ **Electrical interconnection:** Determine distance and route to the interconnection point, and placement of electrical equipment including combiner boxes, disconnects, inverters, and other BOS components.
- ☐ **Orientation:** Choose a tilt for the array that balances maximizing production and maximizing usage of the area (steeper tilts mean rows of modules must be further apart due to interrow shading).
- ☐ **Height:** Consider snow buildup and vegetation growth to determine the minimum height to the array's lower edge.
- ☐ **Layout:** For multiple rows, plan spacing according to shading calculations, access requirements, and trenching routes.
- ☐ **Maintenance:** Plan for dealing with vegetation growth and access to the modules for cleaning.

A Ground-Mounted Solution

Down a quiet gravel road in a small community in the piedmont of North Carolina, Joe Gamble and Suzanne Thompson's house often loses utility power during too-common hurricanes and ice storms. Their first priority was PV-powered battery backup for the well pump, but they also wanted to power as much of their residence as possible with renewable energy.

Their home—a geodesic dome—was particularly problematic for a roof-mounted PV system. The multiple azimuths and tilt angles of the curved dome would have meant installing modules at wildly different orientations or with a complicated rack attachment system—not usually a wise PV design decision (although microinverters or module maximizers might help alleviate the energy production aspects of this problem).

The siting focus turned to a field behind the house. But the field had its own issues: it was covered with brush, included a perilously steep western slope, and was bordered to the north by a utility right-of-way and on the south side by a row of evergreen trees.

Type of Mount

For PV arrays situated in fields like Joe and Suzanne's, there are two choices—pole mount or ground mount. Pole-mounted PV arrays sit atop a heavy, steel pole (usually 6 or 8 inches in diameter) that is anchored in yards of concrete. Ground-mounted racks have multiple smaller supports that secure the array, and usually sit closer to the ground. The slope of their field was too steep for concrete trucks or other heavy equipment, ruling out the pole-mounted solution.

Courtesy Honey Electric Solar (2)

DPW Solar provided the engineered rack system, which Honey Electric Solar installed on the steep slope.

Honey Electric Solar designed and installed the 2.8 kW PV system with two, side-by-side ground-mounted DPW Solar racks. Each rack accommodates eight, 180 W Evergreen PV modules that power an OutBack battery backup, grid-tied inverter. The Gamble array was limited to four modules in a series string, due to the module voltage, temperature extremes, and charge controller voltage window. If the strings had been limited to three modules instead of four, it would have meant splitting a string across the two racks.

Footers were reinforced with rebar and inspected prior to pouring concrete.

Poured concrete piers provide solid footing for mounts and BOS components.

Courtesy Honey Electric Solar

Cross-bracing keeps the plane of the modules from flexing under wind or snow loads.

Courtesy Joe Gamble

Courtesy Peltz Power

Compared to roof-mounted arrays, which are typically installed inches above and parallel to the roof plane, ground-mounted arrays have access to greater airflow, resulting in cooler operating temperatures and higher production.

Specifics to Consider

Every site is unique, and every mount design will be, too. For example, an array located in an area that receives heavy snowfall should have ample ground clearance so that snow can slide off, accumulating below without shading the modules.

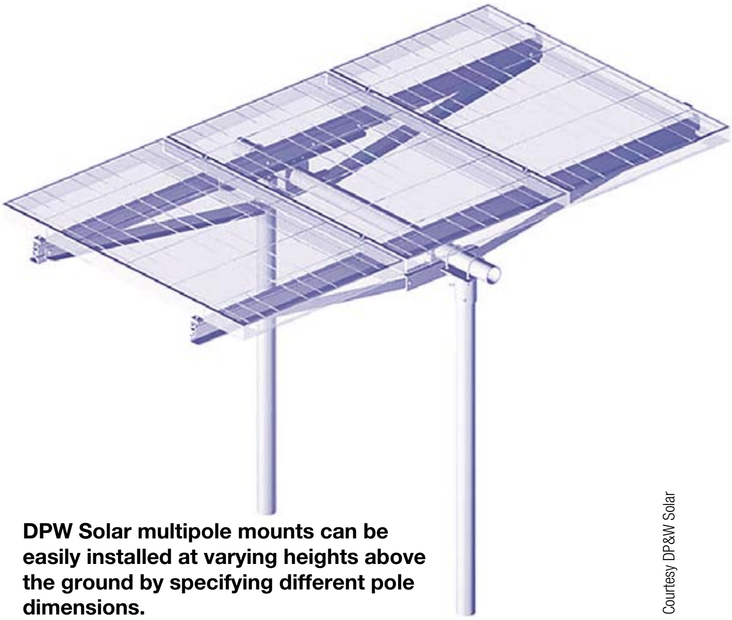
In addition to site-specific considerations, the tilt angle of the array is a key factor. While adjustable legs are a common option with many ground-mounts, it isn't nearly as easy as adjusting a pole-mounted array. Most pole mounts are balanced and have a single point of tilt adjustment, which a person can handle alone. Ground-mounted racks have multiple bolts, and the weight of the modules is resting on legs that have to be adjusted simultaneously or each leg a little at a time. This means at least two people can be needed for adjustments, or the process becomes arduous.

For a design starting point for a single-row, grid-tied array—that most commonly has a fixed tilt—use NREL's online PVWatts calculator to find the angle that gives the highest possible annual energy (kWh) estimate for your site. Deciding on a fixed tilt angle for the array can be tricky if you're off-grid or have multiple array rows within close proximity.

For setting the tilt of off-grid arrays, consider when loads are heaviest or the fewest sun-hours are available and choose an angle close to perpendicular to the sun's rays for that time of year. If no set tilt angle can meet the consumption demand year-round, then calculate what fixed tilt will most likely reduce generator run time via a comparison of seasonal production at different tilts versus seasonal loads.

For ground mounts with multiple rows in close proximity, the choices become even more complicated. An array set at lower tilt angles means interrow spacing can be narrower, since the shadow cast by each row is shorter—and more rows can fit into a smaller footprint. The trade-off is that as module tilt decreases below the optimum, array energy production will decrease as well. A good starting point that balances the two goals for a multirow array is to set the tilt at latitude minus 10°. Manufacturers can assist in calculating interrow shading and spacing where necessary.

Positioning the inverter(s) and other balance of system (BOS) components is another critical design decision, especially when the goal is to keep voltage drop to a minimum. Higher voltages with lower currents allow smaller wire sizes, which means money saved. For high-voltage, grid-tied residential arrays using string inverters, the DC voltage will nearly always be higher than or about the same as the inverter AC-side voltage—which means keeping the longer runs of conduit and wire on the DC side of the inverter can be a good design decision. The



DPW Solar multipole mounts can be easily installed at varying heights above the ground by specifying different pole dimensions.

Courtesy DP&W Solar

Ballast Mounts: Not Just for Flat Roofs Anymore

Ballasted mounting structures have traditionally been used on flat commercial-style roofs, where penetrating the roof surface is undesirable or impossible. Instead, a heavy ballast, often concrete blocks, sits in trays attached to the mount to firmly hold the array in place. Ballast weight is based on the site's design wind speed and other factors that affect the wind loading and pressure on the system. The building also must be structurally sound to support the added ballast and system weight.

Ballasted mounts are now being used on the ground, too. In places like brownfields that have contaminated soil, or landfill sites that have been capped, a ballasted system can be the only way to secure an array without penetrating the soil—turning a previously unusable site into a clean energy generation plant! Ballasted systems also work well in places where the soil is extremely rocky. For environmentally sensitive sites, a ballasted system can be more easily moved. Even abandoned parking lots can accommodate ballasted PV arrays without needing to tear up the paving. Ballasted ground mounts do not accommodate sites with more than a 5% slope.

The ballast used for ground-mounted arrays is locally sourced, and can be sand bags, paver blocks, or a precast concrete form specifically designed for the mount. Depending on the ballast racking system used, the site may not require heavy machinery or concrete pouring, and may require only minimal surface prep during installation.

Courtesy Tom Barnes

Concrete pavers or other blocks can be used to keep a ground-mounted array from being lifted by wind.

positioning of array BOS components will directly impact where conduit will be buried and how the array can be accessed for maintenance.

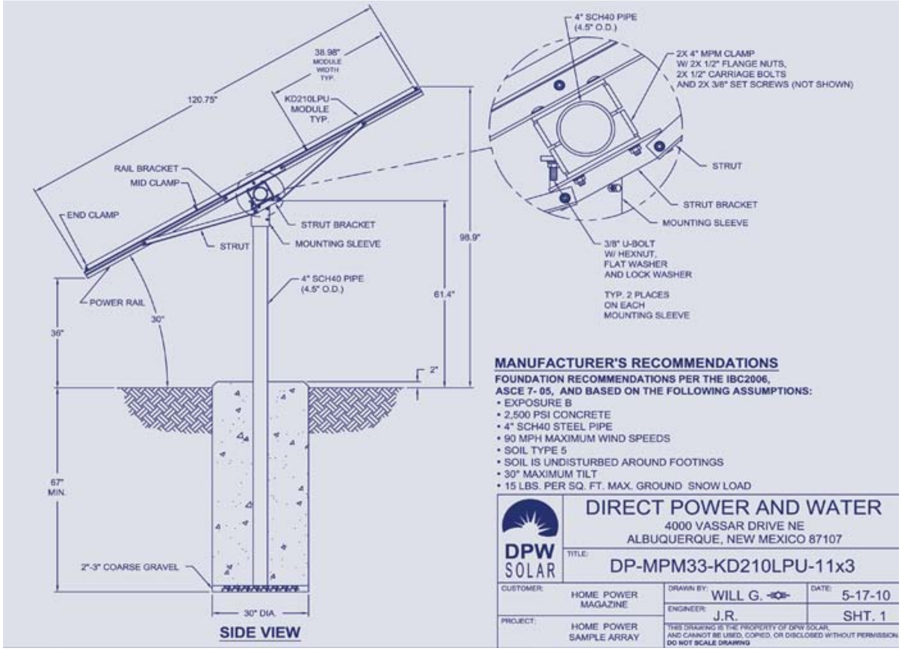
Code & Maintenance Considerations

Section 690.31A of the 2008 *NEC* specifies that PV wiring should not be readily accessible. For ground and pole mounts, that means either containing it in a raceway (which is possible when the modules have junction boxes that accommodate conduit) or by other means—the usual solution being locating the array behind a fence that does not shade the array. A fence can be a good choice for other reasons, such as in high-profile areas where theft or vandalism might be an issue. Several ground mounts have wire-management channels, into which PV wires can be safely tucked. These channels are either integrated into the design or offered as an option. These are not frequently UL-listed as a raceway, so the authority having jurisdiction over the installation might question their use for wire management.

The grounding for ground-mounted arrays also should be carefully considered. *NEC* Section 690.47D requires grounding electrodes connected directly to the array structure at the location of the ground mount. Exposed, non-current- carrying metal parts that may become energized in a fault situation, like module frames and rack rails, also must be grounded and connected to the grounding-electrode system. It is best to verify your grounding techniques with your inspector beforehand.

One of the biggest challenges for ground-mounted systems is keeping the surrounding area free of array-shading vegetation. Solutions include gravel, landscape fabric, and mowing. Sheep have been successfully used to keep the area around the array clear (but don't use goats, which will climb on the array and try to chew on conductors)! Mowing or

All rack manufacturers should be willing to supply custom drawings of their engineered systems. If needed for the local inspector, stamps from professional engineers can be provided.



Courtesy DPW Solar

string trimming should be done carefully, as thrown rocks can damage the panels. Another factor to consider is the permanence of the installation—some sites, especially in land trusts or farmland, require a plan for future removal of concrete piers and associated structures.

Finding a Manufacturer

Some manufacturers design mounting structures only for "larger" arrays or split their product lines into residential, commercial, and utility-scale solutions. If in doubt, check their Web site, and get in touch with them. A manufacturer should be easily accessible by phone or email, so it is worth the trouble to call a few and discuss upcoming projects to get a feel for how responsive they will be.

Access

Rebekah Hren (rebekah.hren@o2energies.com) is a licensed electrical contractor and NABCEP-certified PV installer living in Durham, North Carolina. Rebekah teaches PV system design and installation classes, and co-authored *The Carbon-Free Home*, a book on residential energy efficiency retrofits. Her newest book, *Solar Buyer's Guide for Home and Office*, will be available in October.

Manufacturers:

AEE Solar • www.aeesolar.com

Applied Energy Technologies • www.aetenergy.com

Conergy • www.conergy.us

DPW Solar • www.power-fab.com

HatiCon Solar • www.haticonsolar.com

Hilti • www.hilti.com

Next Generation Energy • www.zillarac.com

Panel Claw • www.panelclaw.com

Professional Solar Products • www.prosolar.com

Solar Flexrack • www.solarflexrack.com

SunLink • www.sunlink.com

Unirac • www.unirac.com