MARCH/APRIL 2008

fabric ARCHITECTURE

DESIGN FOR SUSTAINABILITY

SUSTAINABLE FABRIC 102
MATERIALS & TECHNOLOGY

PV + fabric + sun = Vegas green car park

Geotextiles help save the earth

New materials for sustainable design

AIA Learning Unit: Erosion control

IFAI publication

Bright(er) shiny day

Fabric complements the sustainabl

BY Craig G. Huntington

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Logan Granger, SunPower Corp.
and Steve Proehl

The high reflectivity of architectural fabrics has long been used to minimize heat gain in buildings constructed in warm climates. At Las Vegas Springs Preserve, this same high reflectivity is employed to bring more daylight to overhead photovoltaic arrays and substantially improve their energy production. Springs Preserve, located at the site of the original spring where Las Vegas was born, is a public visitor center with displays and events focused on sustainability in the desert environment. Its six new photovoltaic arrays, constructed over grade level parking, provide the center's most dramatic display of sustainable building technology.

Evolving strategies for photovoltaic performance

The growing market for photovoltaic (PV) arrays has brought with it the exploration of increasingly sophisticated means of supporting and configuring PV panels, as well as greater diversity in siting of photovoltaic arrays. Most are constructed at grade or on building roofs. However, ground mounted arrays consume substantial acreage, reducing the effective sustainability of such installations, while the unsuitability of many building roofs to PV array installation limits roof top installation as a means for satisfying the growing market for solar power. Carports are one of several emerging venues for array installation. By using framing to support solar panels overhead of outdoor parking areas, the land becomes "dual use," and no additional site area is consumed by the solar array.

Consideration of the strategies for optimizing the positioning and orientation of PV panels within an array provides the background for understanding how fabric is used to

inspired photovoltaic system at Springs Preserve, Las Vegas

enhance the output of the arrays at Springs Preserve. Panel orientation relative to the sun strongly influences photovoltaic output, and panels are sloped perpendicular to the direction of sunlight for maximum power gain. Shading of any part of the array critically impacts output, as shading not only reduces the power gain from the shaded panels, but has the disproportionate effect of reducing the efficiency of all of the panels grouped into an electrical string.

Strategies for high efficiency in PV array design must therefore carefully consider panel orientation and shading. The most basic array configuration uses panels that lay flat on grade, rooftop, or supporting structure. These flat arrays may be economical to construct, (and they allow panels to be closely spaced without shading), but their oblique orientation to the sun means that they offer the lowest output per panel. To improve output, some designs tilt the panels towards the south so that the panel slope is a compromise between the ideal slope at the summer solstice (when flat panels are highly efficient) and the winter solstice, (when substantial slope, depending on latitude, may be optimum.) (Fig. 1, pg. 56.) A slope of about 15° provides optimal overall efficiency in moderate latitudes. Space must be provided between the panels in order to avoid shading in certain sunlight conditions, so that tilted arrays may make less efficient use of space than flat arrays.

More advanced arrays are designed as "trackers" that rotate the panels to follow the path of the sun during the course of the day (Fig. 2, pg. 56.) Whereas tilted panels improve winter PV performance, tracker panels provide improved performance early and late in the day. The most sophisticated arrays employ both tilting and tracking to optimize power output.

Sun beams down on the Springs Preserve car park but little reaches the cars themselves as the overhead mesh fabric shading elements of the PV system block the solar rays. The combination of arrays of PV panels and fabric mesh is one strategy to improve efficiency of the solar collector system at this visitor center near Las Vegas, reaching up to 18% increased power.

Further increases in array power output have been recently achieved through the use of bifacial panels, which are photovoltaically active on bottom as well as top, so that light reflected from the ground or other surfaces below the panels also contributes to power output (Fig. 3, pg. 57.) The gain associated with bifacial panels is a function of several factors:

- Albedo, a measure of the portion of light striking the surface beneath the panel that is reflected back upward. (Typical albedos range from 0.10 for foliage or asphalt, to 0.30 for concrete, up to approximately 0.80 for snow.)
- Panel spacing. When panels are closely spaced, insufficient direct sunlight passes between the panels for substantial reflection of light on the panel bottom sides to occur.
- Panel height above the reflecting surface. Panels that are too close to the reflecting surface restrict the amount of light that can be reflected to the underside of the panels.
- Obstructions. Framing or other obstructions below the PV panels that cause shading will reduce the efficiency of all panels grouped into an electrical string.

Spacing the panels widely increases the total surface area required by a given number of panels, but wide spacing, in combination with 457.2mm or more of elevation difference between the panels and reflecting surface below, results in the highest output for individual bifacial panel.

Fabrics boost power output

Panel height and spacing, along with obstruction free installation, are geometric considerations critical to maximizing the output from bifacial panels, but a strategy for their effective use must also consider how albedo can be raised to increase the light energy reaching the bottoms of the panels. Here, the high reflectivity of architectural fabrics, which is so useful in reducing building energy use by keeping building interiors cool in sunny climates, comes into play on the production side of the energy equation. At Springs Preserve, tensioned fabric membranes were installed to create a reflective interlayer between the parked vehicles and overhead arrays of bifacial PV panels. The gain in photovoltaic output associated with fabric membranes is primarily a function of the high albedo of fabric relative to that of the typical asphalt or concrete parking lot paving that it replaces as a reflecting surface.▪

PV panels rotate to match the sun's angles throughout the day to maximize power output, but tensioned mesh fabric swathes beneath the arrays reflect light to the backsides of each panel, thus boosting power output by an additional 6% beyond what a single-sided system might produce.

Springs Preserve has a total of six PV arrays constructed over visitor parking areas to create dual land use (above.) The panels tilt to the south for improved orientation to the sunlight in five of the six arrays. Two of the arrays are designed to track as well, through the use of steel pipe "torque tubes" that rotate the panels from a slope 45 degrees to the east in the morning to 45 degrees to the west in the afternoon (Fig. 2.) While panels in all of the arrays are bifacial, the two tracker arrays also incorporate fabric membranes installed over the heads of parking area users but below the PV panels. In the four arrays without fabric, the bottom surfaces of the bifacial panels are reliant on the low albedo of the concrete paving. Testing by the panel supplier Sanyo on prototype panels indicate that the bifacial panels have a power output approximately 6% greater than that of single sided panels in similar conditions. By contrast, Sunpower's own testing on prototype panels indicates that bifacial panels over white mesh fabric increase power output approximately 18%.

Shaping for economy and efficiency

The need for uniform reflectivity dictated that the fabric be nearly horizontal throughout its surface, as did the need to place the fabric both overhead of the parking and below the array while at the same time avoiding the added expense of raising the elevation of the array. PV contractor Sunpower initially conceived the fabric as flat and uncurved membranes, as a result, and proposed a white mesh as a means of allowing water drainage on the flat panels.

A flat piece of woven fabric, while very strong in resisting tension loads that pull on it directly, is unable to carry a load across a span unless it is curved along its length, in the manner of a suspension bridge cable. However, through the use of rigid mast or beam elements to manipulate its shape, it is possible to pretension a fabric surface into a curved shape so that in can successfully resist both upward and downward wind, live, and snow loads. Fabric membranes are typically curved into "anticlastic" shapes like that of a saddle, which rises in the middle from side to side and sags in the middle from front to back. Upward loads are resisted by tension in the fibers that "hog" or rise along their length, while downward loads are resisted by the sagging fibers spanning in the opposite direction. The load resistance of these anticlastic forms is dependent on curvature about opposing axes of the membrane.

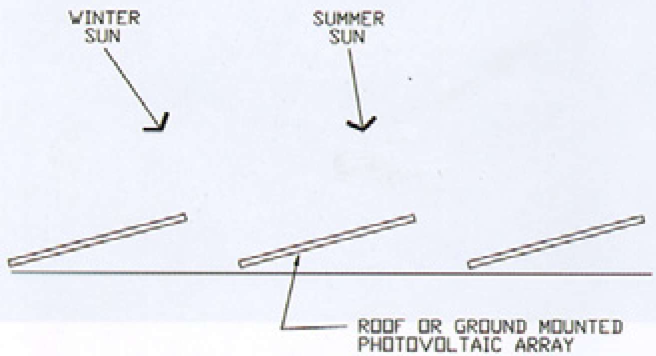


Fig. 1 An improved configuration vs. flat layout.

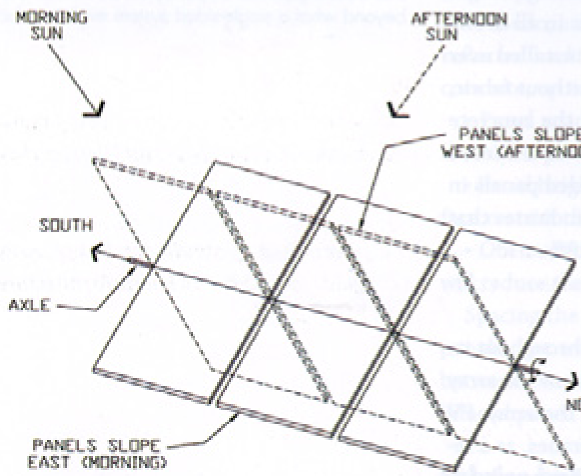


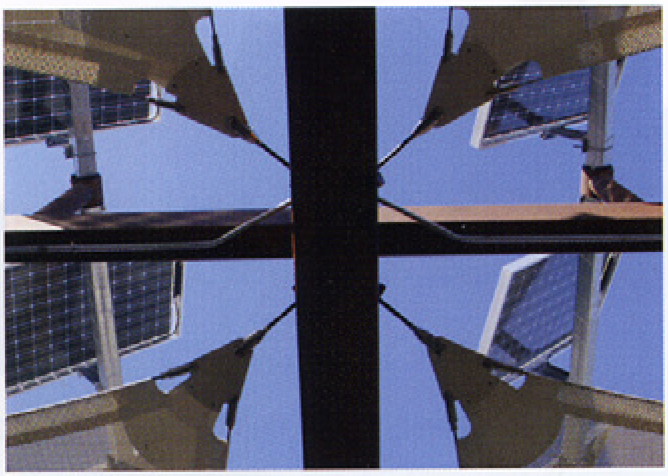
Fig. 2 A tracker arrangement improves PV performance both winter and summer.

As the curvature in the fabric membrane is increased, the resulting tension stress in the fabric and the loads on the supporting structure under load decrease proportionally.

Not surprisingly, initial analysis of the flat membranes proposed for Springs Preserve by engineer Huntington Design Associates found high stresses in the fabric and cables, excessive loads on the supporting structure, and large deflections, demonstrating the inefficiency of flat membranes in resisting loads. To achieve curvature in the membranes, the rectangular fabric panels were redesigned with six attachment points to the supporting steel. The four corner points connect at the same workpoint elevation on the top surface of the primary steel girders. Intermediate attachment points along two opposing sides, though, are secured at lower elevation. The photo far left, above, shows the intermediate anchorage points of the center panels secured to the underside of the main girders and the intermediate anchorages of the side panels secured to the sides of the steel supporting columns. The offset in attachment point elevations forced the membranes into anticlastic curvature, and the reanalysis that followed showed the payoff in reduced fabric and cable stresses and supporting steel loads.

The South Elevation of one of the arrays (Fig. 4) provides a different perspective of the curved membrane shape. It also shows other important features of the photovoltaic design strategy: the range of rotation of the trackers, the positioning of the membrane beneath the array, and the gaps that are provided between the rows of panels on each torque tube to allow light to penetrate between the panels and be reflected from the fabric back up to the panel bottom.

Analysis of the curved membrane design indicated that the some of the fabric panels would still deflect sufficiently at midspan under moderate wind to impact the large transverse girders above them. Valley cables were therefore added on top of the fabric between the intermediate anchorages. These cables pull the fabric into a lower profile along the valley line, not only preventing the fabric from touching the steel above, but also providing a more visually dynamic curvature. The slope of the fabric remains small near midspan, even after these modifications, so that the danger of ponding was not eliminated, and the final design therefore retained the use of mesh fabric. The mesh provides a "soft" barrier to vision and light, both relieving the visual clutter of the arrays overhead and providing gentle shading of vehicles and visitors below (photos above, center.) Besides increasing the comfort of those using the parking areas, the shading provides a small ancil-



lary energy benefit: drivers can turn their air conditioning down as they exit the parking on hot days.

In order for the fabric to provide economic value to the project, it was important that its installed cost not exceed the value of its contribution to energy generation. Simplicity in fabrication and erection were therefore critical elements of the design strategy. Structural bay widths are generally uniform, so that fabric contractor Eide Industries could maximize the speed and economy of membrane fabrication.

Fabric panels are bordered by galvanized steel catenary cables, and the catenaries are secured to membrane plates at the corners of each fabric panel that are in turn anchored to the supporting steel (photo above, right.) Simplicity, repetition, adjustability, and visual elegance were the goals of the connection design. All membrane plates and stainless steel Frontier jaw fittings are identical, and the stainless steel all thread rods anchored to the supporting steel provide both tensioning mechanisms and adjustability for fit up. The intermediate panel connection points employ custom fabricated Frontier fittings, in which the catenary cable rides across the head of the valley cable spade end fitting (opposite, far left.)

The fabric panels extend past the edges of the array to provide their benefit throughout, but the gaps between fabric panels created by the catenaries reduce the effective albedo beneath a small portion of the panels. The loss in power production was deemed acceptable, in view of the improved economy, speed of erection, and visual richness provided by the curved fabric openings. The enlivening visual character of the fabric catenary edges is particularly evident at the edges of the structure (opposite, right), where the playfulness of the membrane contrasts with the hard lines of the steel structure. The steel was treated with muriatic acid to cause oxidization, then coated with a clear sealant. Its finish mirrors that of other steel elements throughout Springs Preserve, and complements the colors of the surrounding desert.

The Springs Preserve carport PV arrays provide a visually dramatic and environmentally effective use of solar power, and the incorporation of fabric membranes into the array structures represents a step forward in both the photovoltaic performance and architectural quality of these applications. Ongoing testing will provide more concrete data about the effect of fabric membranes on the performance of bifacial PV arrays, but development of this technology continues in the meantime, and the team of photovoltaic contractor Sunpower and engineer Huntington Design Associates have recently completed a second structure using similar design strategies at the Carmichael, California Water District Headquarters Building. FA

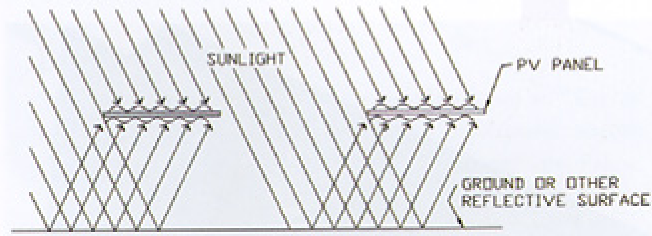


Fig. 3 Bifacial PV panels have high efficiency.

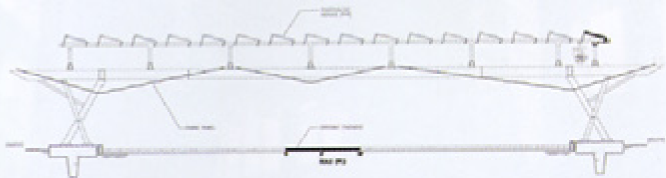


Fig. 4 South elevation showing PV arrays and reflector fabric.

Craig G. Huntington, S.E., is principal of Huntington Design Associates, Oakland, Calif., and a regular contributor to Fabric Architecture.

PROJECT DATA

Client: Las Vegas Water District
General contractor: Sunpower Corp.
Fabric structure engineer: Huntington Design Associates Inc.
Fabric structure contractor: Eide Industries Inc.
Steel structure engineer: Material Integrity Solutions Inc.
Mechanical & electrical engineer: Sunpower Corp.
Fabric: PVC-coated polyester, Ferrari 492 mesh

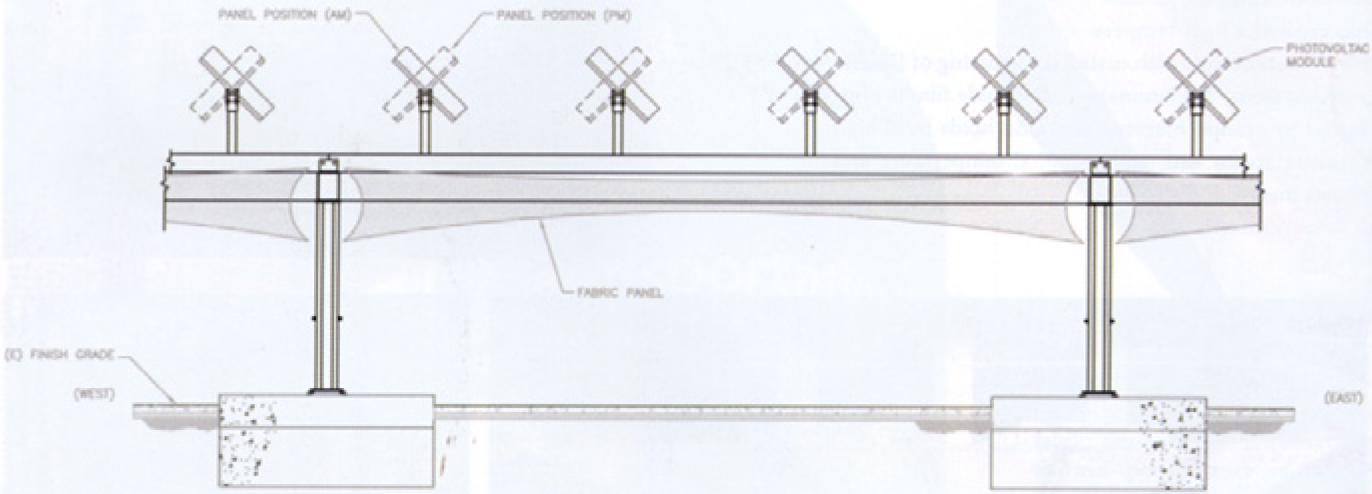
**In the extreme case, albedo may be increased from the 0.10 of asphalt to the 0.75 of a typical solid, white fabric. At Springs Preserve, where parking areas are paved in concrete and the fabric is a white Ferrari mesh, albedo was increased from 0.30 to 0.65.*

Reflective panel for photovoltaic system

A tensioned valley cable (center in photo at left) and edge cables help provide enough curvature in the membrane panels to resist loads. Simplicity, repetition, and adjustability of the fabric panels maximizes the speed of assembly and economy of fabrication for the Las Vegas Springs Preserve (see pg. 52.)

All membrane plates and stainless steel jaw fittings are identical, and the stainless steel all thread rods anchored to the steel supports provide both tensioning mechanisms and adjustability for fit up.

Detail shows the range of rotation of the photovoltaic trackers, the positioning of the membrane beneath the PV arrays, and the gaps that are provided between the rows of panels as a result of the tensioning. These gaps allow light to penetrate between the panels and be reflected from the fabric back up to the PV panel bottom.



SOUTH ELEVATION
SPRINGS PRESERVE PHOTOVOLTAIC ARRAYS

PROJECT DATA

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Fabric structure engineer: Huntington Design Associates Inc.

Steel structure engineer: Material Integrity Solutions Inc.

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