SKYLINE solar

SCALABLE SOLAR POWER

Whitepaper

Introduction to High Gain Solar

A New Architecture for Low Cost, Highly Scalable Silicon PV

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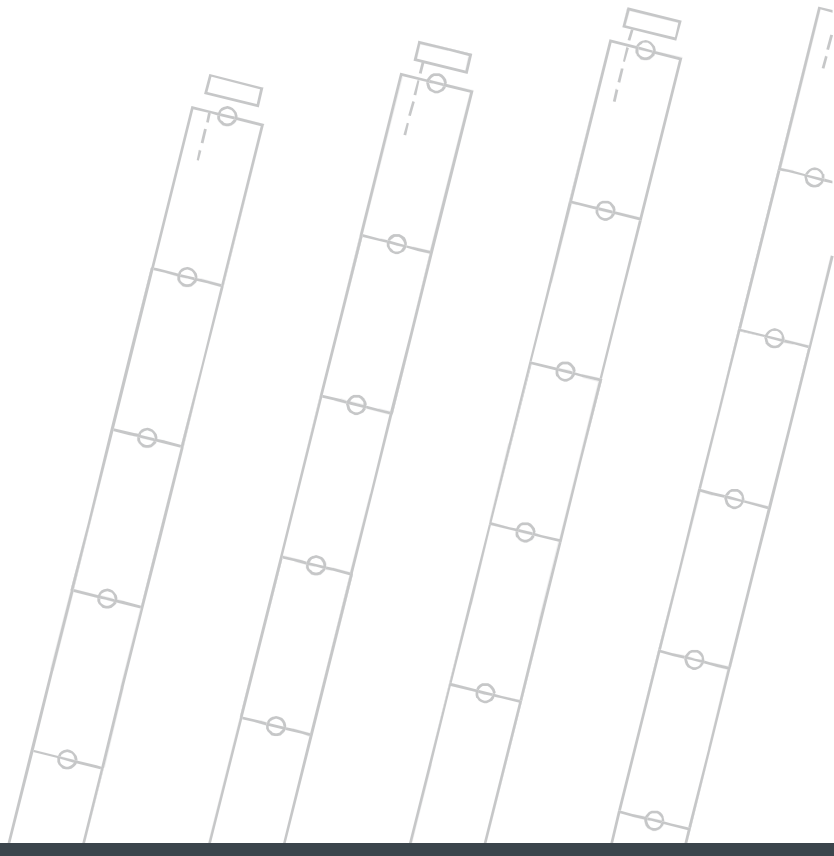


Overview

Skyline Solar has developed its patented High Gain Solar (HGS) architecture for grid connected commercial, industrial and utility scale solar markets. As the solar industry matures customers value energy yield and cost more than peak “nameplate” rating. High Gain Solar (HGS) describes a series of system level design elements which drive lower installed cost and higher energy yield relative to traditional fixed tilt PV. The movement to HGS started with the adoption of high efficiency monocrystalline silicon cells and tracking which increases energy yield and now includes durable reflective materials, lower cost panels, convection cooling, string & shadow management, streamlined installation and maintenance and a number of other improvements. Systems which combine one or more of these elements are considered to be high gain.

Skyline HGS is a total systems solution which combines opportunities along the entire value chain from raw materials to system design, manufacturing, shipping, installation, operations and maintenance and end of life recyclability. HGS shifts the economics of photovoltaics (PV) towards the cost of thin film ($/W = balance sheet) while providing the performance (kWh/yr = cash flow) and longevity of high efficiency tracked silicon in sunny climates. HGS also provides unmatched scalability from a manufacturing capacity and field installation perspective.

Skyline is driving towards general availability in late 2009 based on over a year of field testing and extensive reliability regimen. The company has been running its HGS arrays since early 2008 and has completed a grid connected demonstration project for a customer in San Jose, California, which validates key HGS design concepts. The following paper describes the high level concepts around HGS and how it moves the cost of solar towards grid parity while empowering and stretching the industrial base to deliver greater global scale for solar power.

Figure 1: High Gain Solar Demonstration Plant

Target PV Markets

As the solar energy market evolves from residential rooftop and off grid installations towards a much richer set of applications, different technologies will command advantages in different markets. Two key dimensions determining which technology is best suited are climate and system size. For example, space constrained roof-mount applications in sunny climates are best suited to high efficiency fixed tilt panels whereas roof and ground mount

applications in less sunny environments tend to favor thin films which work well in low light conditions. Thin film scales well into the tens of Megawatts but efficiency and energy density are much lower than high efficiency silicon.

The market for large ground mount systems using silicon continues to evolve quickly, particularly (but not only) in distributed generation applications where land is valuable. The ability to drive higher energy density and lower energy cost makes tracking important in these areas. For example a large fraction of the PV system capacity installed in Spain in 2008 went into tracked systems and many of the large systems being installed in California, Southwestern US and Southern Europe are now being tracked. Other candidates for tracking include North Africa, the Middle East, Australia and parts of Asia.

CSP has attracted renewed interest for very large, utility scale deployments based on the prospect of low delivered energy cost and storage. If realized, this provides a measure of dispatchability valuable to utilities. But obstacles to CSP include large up front capital investment, very high water consumption and long design and deployment cycles.

HGS combines the best aspects of tracked PV and tracked CSP (more details later in this paper) making it the leading solution for sunny climates. HGS systems are optimized for 100 kW to multi-Megawatt tracked ground mount applications and are ideal for larger systems. HGS benefits include the following.

- Levelized Cost of Energy (LCOE) competitive with the grid— total installed system cost achieves aggressive targets to be cost competitive.
- Validated reliability—system leverages proven materials and manufacturing processes. Tested and certified by third party test labs
- Ease of installation and commissioning— rapid installation, no specialized equipment or training required, use of local labor sources.
- Rapid manufacturing scalability and flexibility—able to leverage large existing regional pools of manufacturing capacity to achieve massive production scale.

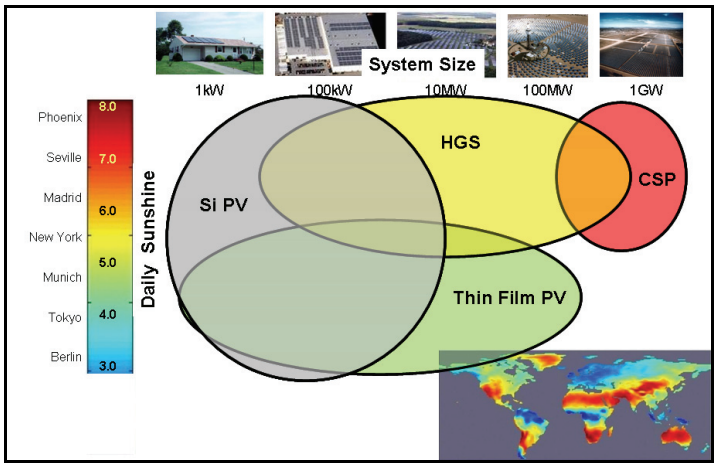
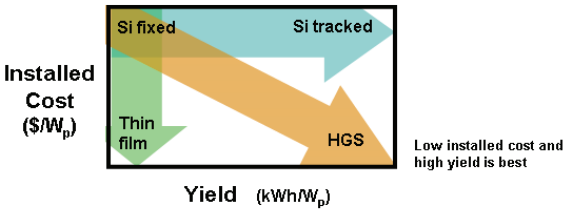


Figure 2: Skyline Solar Market Segmentation Model for 2012

High Gain Solar Opportunity

While most of the solar industry has focused on incremental efficiency gains for cells and larger cell manufacturing capacity, little focus has been paid to total system solutions which drive economic gains across the entire value chain. At a high level there are two paths to better economics. The first is to drive lower installed cost per peak Watt ($/Wp). Cheaper and more efficient cells are a major part of this effort but other opportunities include slashing cost and number of parts per Watt, lower cost panel assemblies, racks, balance of system (wiring, inverters), logistics and simplified installation.
Thin film focuses on the first path by driving the overall cost per Watt peak down using low cost cells. It performs relatively well in less sunny climates like Germany, but it's poor efficiency and requirement for large array area per Watt peak tends to drive the balance of system costs up and makes investment in tracking or other yield enhancements impractical in sunny climates. Both thin film and traditional silicon PV suffer from the "factory in the field" phenomenon where millions of panels and framing components must be hand-assembled into power plants in the field. Little systems level innovation has occurred to streamline this installation process and provide field level scalability.



More Watts$_p$ per Dollar	Thin film	Si tracked	HGS
Cell	x	-	x
Panel	x	-	x
Rack	-	x	x
Balance of System	-	x	x
Installation	-	x	x
Logistics	-	x	x

More Energy per Watt$_p$	Thin film	Si tracked	HGS
Tracking	-	x	x
Thermal design	-	-	x
Light capture	-	-	x
Anti-soiling	-	-	x
String & shadow mgt	-	-	x
Uptime	-	-	x

Figure 3: Opportunities for high gain

The second path to better economics is through higher energy yield per peak Watt (kWh/Wp). Tracking provides up to thirty percent more energy per peak Watt versus fixed tilt systems. Additional opportunities for higher yield include thermal cooling solutions which lower cell temperature, better light capture, anti-soiling, improved string and shadow management and uptime.

Although many companies are starting to include high gain design elements in their products – most notably single-axis tracked high efficiency silicon systems -- the traditional paradigm of component level optimization around flat panels has slowed the movement towards total system level optimization. For example, most panel vendors don't make trackers and tracker vendors don't make panels. Panels are manufactured in the largest practical sizes and trackers end up being generic (often over-engineered) designs which work for a range of commonly available panel sizes. Each set of vendors is constrained to working within its

own sphere of influence, leaving the potential to rethink form factor, cooling and many other opportunities for higher gain untapped.

Skyline High Gain Solar – Building on Proven Technology

Skyline HGS redraws the design boundaries to provide a total system solution – rebalancing each layer of the solution from raw materials through panel and system design, manufacturing, installation and maintenance and end of life -- but continuing to leverage proven materials and methods throughout.

Skyline's approach can be seen as the next logical step beyond traditional PV and CSP– combining the best concepts from each industry while fixing weaknesses of each. It draws on trusted silicon cells but makes better use of them by reducing the amount of material required per Watt. It also improves cooling to enable higher cell operating efficiency and it more tightly integrates the racking and tracking function for simpler deployment and lower operating costs.

Skyline HGS takes advantage of long reflective troughs and single axis tracking proven out in the CSP industry over decades of operating experience. But unlike early CSP designs which used heavy reflective structures (silver coated glass mirrors), HGS uses sheets of low cost durable reflective metal encased in oxide layers to ensure high durability.

Because of their extreme resource requirements (hundreds of thousands of gallons of water per Megawatt hour), CSP systems have generally been conceived only for central power plants requiring large up-front design and capital investments. HGS is based on much smaller and more modular array building blocks which can used in plants ranging from less than a hundred kilowatts to many Megawatts with capital investment commensurate with size. It works well in distributed applications behind the retail meter.

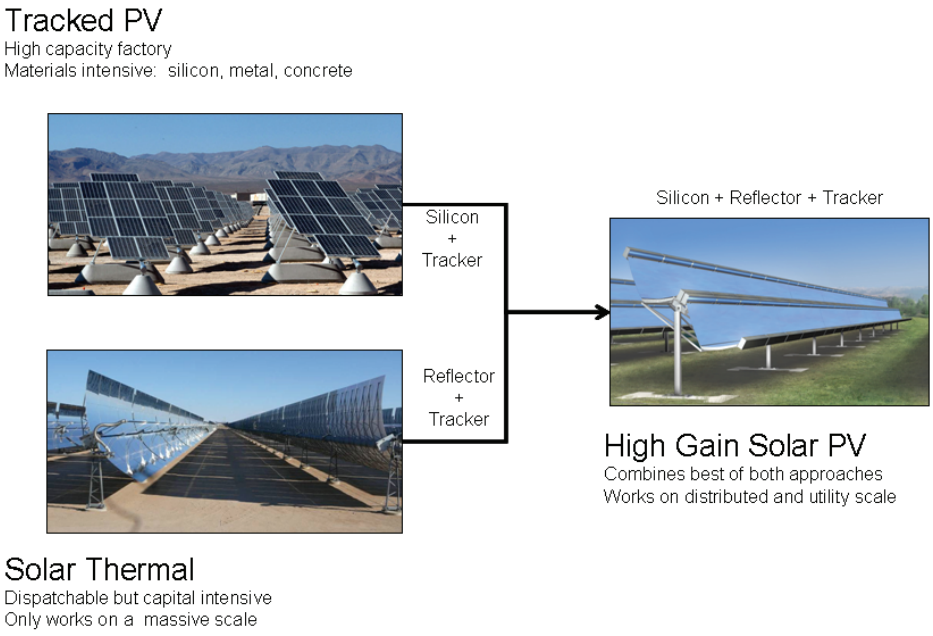


Figure 4: Evolution from Tracked PV and CSP to High Gain Solar

Skyline's Design

- HGS Array -- At the heart of Skyline's patented HGS system is the HGS Array containing a Reflective Rack, four rows of High Gain Solar Panels running along the length of the system, shared tracker, foundation and coupling hardware attaching it to the next array in a column.
- Reflective Rack – The Reflective Rack serves two functions. It provides structural support for the panels – similar to a traditional solar rack – and adds the additional function of collecting and reflecting light from a large aperture onto the much smaller surface area of HGS panels. Initial systems have a concentration factor of roughly ten times.
- Each Reflective Rack is constructed from four gently curved sheets of metal running along the top of the structure and a series of ribs and struts on the bottom. The top surfaces are covered with a thin highly reflective metal coating encased in oxide layers to ensure high durability. This technology was developed and tested over many years in the lighting industry. The overall structure forms a stiff, material-efficient space frame similar to structures used in the automotive and aircraft industries. The result is lightweight enough to be installed in the field without the need for heavy equipment.

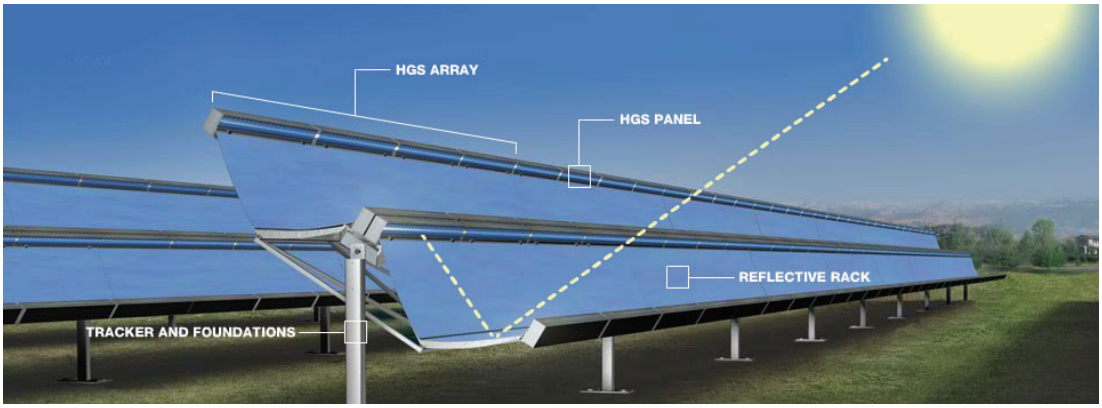


Figure 5: Skyline HGS Design

HGS Panels -- HGS panels are manufactured with the same materials and processes as traditional solar panels but are much smaller in size. They include a backing plate, silicon cells, encapsulant, glass cover plate and junction box. One feature of the HGS panels not found on other panels is a passive metal heat sink which allows passive convection cooling through open air channels. This cooling solution allows HGS cells to run at similar or lower temperatures and higher efficiencies than traditional flat panels even with roughly ten times the current density. Traditional flat panels have no thermal solution and tend to lose efficiency during peak afternoon sun when heat trapped behind the panel drives cell temperatures up.

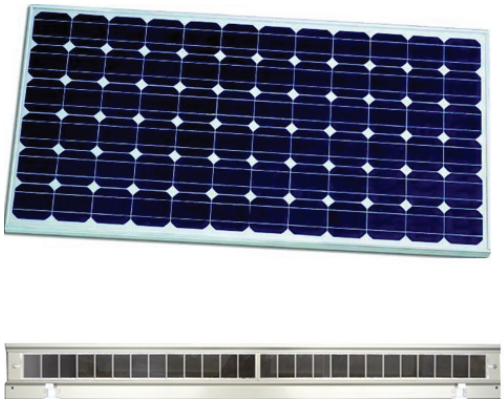


Figure 6: Comparison of traditional silicon flat panel (top) vs. Skyline HGS panel (bottom)

Columns -- Reflective Racks are installed in long mechanically coupled columns with adjacent arrays sharing mounting poles and foundations. The system includes a simple highly integrated single-axis tracking system which rotates long columns of arrays to follow the arc of the sun from sunrise to sunset. Multiple columns are placed side by side to create solar fields.

Traditional PV	High Gain Solar Approach
Rack provides structural support only	Reflective Rack provides both structural support and light capture
Large PV panels perform both light capture and energy conversion	Small HGS Panels optimized purely for energy conversion
Many small components assembled together in the field	Small number of pre-manufactured sub-assemblies installed in the field

Figure 7: Comparing Traditional PV and Skyline HGS

Advantages of Skyline's HGS Approach

- *10X the energy per gram of silicon* -- 30% of this gain comes from tracking and the rest comes from concentration, replacing silicon with inexpensive durable sheets of metal. The combination of these two design elements dramatically increases the effective output per gram of silicon input and lowers the overall cost of the system. This is accomplished with little impact to the overall efficiency of the system and without introducing excess parts or fabrication steps which offset material savings.

  The separation of light capture using large Reflective Rack surfaces and conversion of light to electricity using small HGS panels allows Skyline HGS to benefit from innovation on two technology roadmaps at the same time – high efficiency silicon and reflective materials.

- *30% more system level energy output* – Tracking enables HGS arrays to run at peak output through most of the daylight hours. This means they deliver more energy during peak afternoon demand when utilities charge their highest rates. From a design perspective Skyline HGS more deeply integrates racking and tracking functionality together into a single structure so customers don't need to do their own design integration.

- *67% fewer parts lowers installation cost* – HGS systems are assembled from a small number of pre-manufactured subassemblies. The panels quick connect onto rails to reduce manual assembly and maintenance steps. This contrasts with traditional PV systems which require the assembly of many small parts.

- *Efficient convection cooling for better operating efficiency* – Silicon cells can produce substantially more energy under concentration as long as they're properly cooled. Lower cell temperature means higher efficiency. HGS panels keep cell temperatures below traditional flat panels under the same insolation, despite much higher current densities and thermal load per unit area. They do this using convection cooling from passive metal heat sinks with vertically oriented air gaps running along the back of each panel. This contrasts with horizontally oriented flat panels which trap heat and lose efficiency during peak insolation. Vertical orientation of the panels also reduces soiling on the cells.

- *High structural integrity with minimal use of materials* -- The Reflective Rack rests directly on posts without any additional framing. The reflectors also double as structural elements. Because of their low curvature, they serve as effective shear panels that contribute torsional and bending rigidity to the Reflective Rack. Arranging the troughs in pairs (with the addition of a planar truss to close the bottom) forms a stiff, rigid tube without shading the reflectors. As a result, relatively simple tracking actuators can efficiently turn long rows of modules at much lower cost than conventional tracking systems. No gaps are needed between racks to accommodate supports. Arrays slot together to form a structurally continuous collector surface, which further suppresses twisting in the wind. The low height-to-aperture ratio minimizes aerodynamic lift.

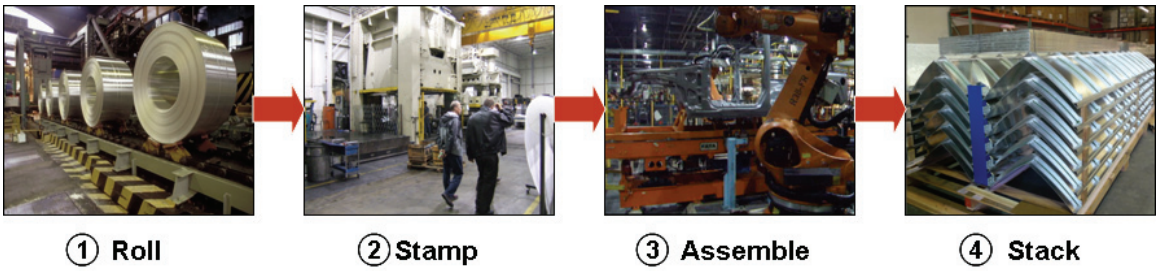


Figure 8: Leveraging Manufacturing Base for Scale

- *Leverages well-established manufacturing processes, infrastructure and supply chains:*

1. Silicon cells available from multiple vendors— the only essential modifications are simple changes to the metallization layer to support high current densities. By concentrating sunlight with a substantial multiplication factor onto the PV technology base that dominates the solar market by electrical output, Skyline's approach can scale the entire market rapidly.
2. Standard PV module manufacturing process to fabricate the receivers—though Skyline's HGS panels are smaller than traditional panels they can be manufactured on the same production lines. The HGS design instantly leverages this capacity by a roughly ten times.
3. Roll-to-roll reflector sheets already produced in high volume for lighting applications—current production (with outdoor coatings) would supply 10GW/yr of PV manufacturing capacity. There are at least three manufacturers of these reflective materials enabling both competition and scale.

4. Metal extrusions, stamps and die casts—nearly every industrial park has the capability to produce the Reflective Rack components. The manufacturing process follows an efficient path from rolled metal through stamping and robotic bonding and assembly. Manufacturing considerations guide every facet of HGS design, such as retaining integral fractions of standard cell and reflector widths; minimizing cuts, joints and machined features; and integrating racking and tracker support into the Reflective Rack.
5. Simplifies logistics and Installation -- Reflective Racks are designed to stack compactly in a standard twenty or forty foot shipping container enabling efficient shipping from factory to field. Rack assemblies are light enough to be installed without the need for heavy equipment. Wiring is integrated into the rack assembly for quick connection.

Design for Scale

The innovation of HGS lies not only in the details of the design, but also in the way that it empowers an efficient, streamlined and swiftly scalable approach to manufacturing operations, supply chain logistics, and installation. Slashing “parts per watt” and “unit operations per watt” must lead, if dollars per peak watt and cents per kilowatt hour are to follow. The result of this philosophy is a modular HGS system whose manufacturing strategy relies only on ubiquitous silicon cells and turnkey PV module production lines, as well as metal fabrication industries that already exist at enormous scale in the US, Asia and Europe. The product design and commercialization strategy cooperate synergistically to promise dramatically lower LCOE and achieve grid parity more rapidly than other technologies, with substantially lower risk.

The HGS architecture links together existing silicon cell, module, reflector and metal parts supply chain and draws on deep regional industrial bases in metal fabrication to quickly expand the collection area under sun. It further maximizes scalability by applying this large multiplication factor on top of the predominant PV base. The approach uses metal to leverage silicon, thereby stretching the generating capacity of silicon cell supply.

Extremely low projected capital costs support the plausibility of a quick capacity ramp from Megawatts to Gigawatts. Because the architecture reconfigures and leverages standard silicon technology, it also captures and amplifies all the independent advances in efficiency, cost and scale of Silicon cells and panel assembly as well as reflective materials industries. Passive reflective sheets will remain a far more effective way to blanket large areas than thin film PV for the foreseeable future.

Environmental Considerations

One final area of consideration is the environmental footprint created by HGS systems relative to traditional flat plate systems. Embodied energy and associated energy payback are key metrics used to judge the impact a technology has on its environment. Embodied energy describes the total amount of energy required to build the system from raw materials through conversion. Energy payback describes the period of time required for the system to generate that amount of energy by converting light to electricity. HGS is better than traditional PV on both counts. This is because HGS is manufactured almost entirely out of recyclable metal structures and uses substantially less silicon-- which requires a high level of energy to manufacture – and hard to recycle materials like glass and encapsulants for a given energy output. At the end of its useful life, the majority metal content of HGS systems can be recycled and re-used.

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