Breaking the Solar Barrier:
Eliminating the Silicon PV Performance Gridlock

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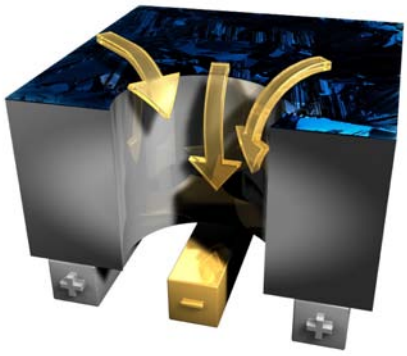
A Whitepaper by Advent Solar

Conventional silicon based photovoltaic (PV) architectures are rapidly approaching a point of diminishing return in garnering efficiency improvements, especially at a system level. Until recently, the learning curve of solar PV delivered around 19% cost improvement (measured in $ per watt) with each doubling of industry production output. This has been the case over the past three decades, but in the past few years steady improvement has been harder to sustain. Conventional PV manufacturing approaches have emphasized cell efficiency and wafer thickness as primary drivers to address the $ per watt equation. However, gains in cell efficiency are invariably frittered away at the system level due to cumbersome manufacturing processes while reductions in wafer thickness are becoming increasingly more difficult. Therefore, conventional PV manufacturing is approaching a gridlock, where system level improvements are becoming marginal. Meanwhile, market demands for PV modules have become more stringent in terms of output energy, quality, reliability, and cost. In order to establish a renewed momentum towards grid parity, creative architectural approaches are required. Advent Solar's comprehensive Ventura™ Technology breaks the technology constraints of traditional silicon photovoltaics, and powers the way to a new generation of silicon PV products. With an innovative architecture, combined with proven principles of manufacturing from the semiconductor industry, Advent Solar is delivering a new generation of module products that are both high value and *Beautiful by Design*™.

Ventura™ Technology: Breaking the Gridlock

Advent Solar® Ventura™ Technology revolutionizes photovoltaic product manufacturing and performance. Ventura is based on a system level architecture that optimizes output value at both the cell and module level. It combines unique back-contact cell architecture (called Emitter Wrap-Through, or EWT) with a highly automated, planar manufacturing process (Monolithic Module Assembly, or MMA). This architecture was inspired by the semiconductor industry that excels in rapid technology evolution. In this way, cell and module performance characteristics are optimized together to deliver modules that have a higher output and are more reliable than conventional modules. Modules made with Ventura Technology are assembled on efficient manufacturing lines with high precision and throughput, resulting in overall reduced costs.



With EWT, charge passes through an emitter diffusion via to contacts located entirely on the backside of the cell.

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Beautiful Inside and Out

Ventura Technology is the industry's only comprehensive system level approach that eliminates efficiency bottlenecks throughout the module manufacturing chain. By eliminating grid lines on the front, the EWT cell maximizes light capture for energy conversion and also creates a visually appealing module surface. Products created with Ventura Technology deliver superior value by providing more energy output, and also address the aesthetic considerations for building integrated photovoltaic (BIPV) markets. Taken together, the architecture's abilities to both maximize light capture and deliver an elegant, visually pleasing design, demonstrate why Ventura Technology is beautiful inside and out…*Beautiful by Design.*

Ventura Technology delivers elegant, visually pleasing products.

Benefits of Advent Solar® Ventura™ Technology

The synthesis of high quality back-contact cells, with an integrated module architecture and highly automated manufacturing delivers the best value silicon solar photovoltaic products in the industry. An overview of some of the key benefits of Ventura Technology follows:

Better Cells: Ventura Technology Emitter Wrap Through, EWT, is a breakthrough cell design that was originally conceived at Sandia National Laboratories and developed into a high-efficiency commercial product by the Advent Solar team of technology pioneers. The patented EWT design produces a more powerful cell by eliminating front grid obstruction and improving light capture. In addition to the clear advantage in energy generation, the EWT architecture enables a revolutionary module manufacturing process. Going to back-contact cell architecture is in itself a fundamental and essential step towards achieving high performance solar architecture. The Ventura EWT Cell Technology uniquely enables an efficient planar module manufacturing process that is highly automated and reliable. Unique cell benefits include:

- Higher conversion efficiency due to front grid elimination
- Better aesthetics due to elimination of unsightly grid lines and improved cell alignment accuracy on module
- More flexible contacting geometry for improved cell and module optimization

Better Modules: Using proven semiconductor-style manufacturing techniques, Ventura™ Monolithic Module Assembly (MMA) Technology enables fully automated module assembly with planar processes for the first time, delivering scalable high volume module manufacturing capabilities. MMA also allows EWT cells to be used in an optimal way by vastly improving interconnectivity within cells and at the module level. Advent Solar modules are designed to be beautiful – inside and out – delivering higher energy output and enhanced building aesthetics. Module benefits include:

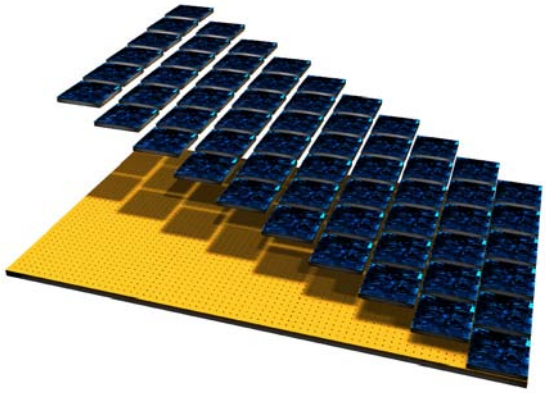
- Highly automated, planar module assembly process
- Maximized output power with minimal interconnection resistive losses
- Precision cell placement allows tighter packing density on module (higher efficiency or watts per area)

Better Manufacturing: Ventura Technology is the best blueprint for designing and manufacturing industry-leading silicon PV solar modules. The blueprint incorporates a comprehensive, system level architecture that preserves high efficiency at all points of the manufacturing chain. In addition, it provides scalability across silicon types and wafer thickness levels. Benefits of our unique manufacturing process include:

- Lower cell processing and interconnect costs than other back contact technologies
- Faster production due to integrated backsheet production with roll-to-roll processing and automated “pick and place” of cells
- Best quality and reliability due to superior yield control and precision manufacturing -- elimi nation of breakage, rework and specification deviations
- Better production throughput due to planar module assembly process, delivering more capacity per factory foot print area
- Enables a better distribution of power output of the product

Delivering Higher Value with Ventura Technology

Today, conventional cell and module technologies are designed and manufactured independently and lack a cohesive architectural framework for system level optimization. Improvements in cell performance are “wasted” at the module level due to efficiency bottlenecks that prevail in the overall system. Typical conventional PV manufacturing processes force-fit cells into module assembly methods with seemingly unrelated, non-complimentary design considerations. The following discussion will lead us through an overview of why Advent Solar Ventura Technology is different, along with some notable advantages delivered by this revolutionary approach.



Ventura monolithic module assembly. Cells are assembled directly to an integrated module circuitry via distributed contacts and selective isolation.

Manufacturing Advantages of Ventura Technology vs. Conventional PV:

Conventional PV	Advent Solar Ventura Technology	Advantages of Ventura Technology vs. Conventional PV
Busbar Contacts	Distributed Contacts	• Lower Contact Resistance • Higher Performance • Lower Stress
Front to Back Contact	Back-Contact	• Reduced Optical Losses • Higher Performance • Planar Assembly • More Continuous Manufacturing
Multiple-Step Tabber/Stringer	Automated Pick and Place Assembly	• Greater Precision of Cell Placement • Higher Production Throughput • Reduced Cell Handling and Breakage • Higher Yield and Reliability • Better Process Control • Higher Cell Packing Density • Improved Aesthetics
Ribbon Interconnects	Monolithic Circuit	• Single Step Assembly • Lower Stress on Thin Wafers • Reduced Part Count • Better Yield

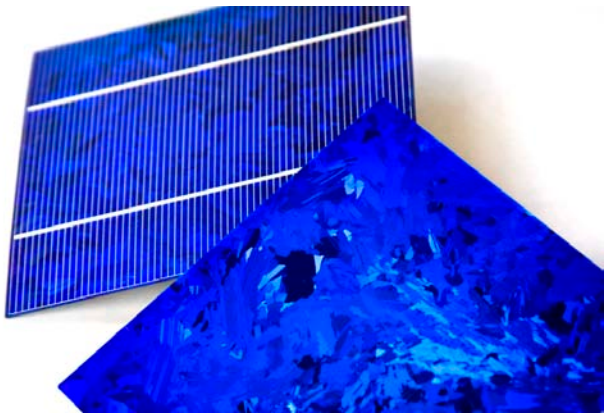
Cost: Gains in cell and module-level performance are becoming increasingly expensive to achieve. Conventional silicon PV manufacturers have a limited number of options for improving performance while simultaneously controlling costs. Since the silicon cost represents a dominant portion of the overall costs, most approaches focus on reducing wafer thickness as a primary avenue for reducing cost. By reducing wafer thickness, the utilization of silicon increases, thereby reducing costs. However, without an efficient module manufacturing process that accommodates thinner wafers, the cost reduction can be negated due to increased breakage and yield losses. As wafers get thinner, the cells become more susceptible to stress and bow resulting in yield fallout—thus increasing costs.

In contrast, Advent Solar Ventura Back Contact Technology opens the door for many new cost improvements; here are a few:

- EWT cell and MMA assembly approaches are accommodative to thin wafers
- With the use of soft handling robotics, the highly automated manufacturing process uses “pick and place” tooling with precision, which reduces cell breakage.
- Integrated module circuitry opens new opportunities for cost optimization of metal circuitry.

Performance: In conventional modules, current is extracted from the cells through small solder connections along long, narrow tabs (interconnects.) Power losses in the interconnects are significant—the cell power is degraded about 4% on average after interconnection and lamination into the module using conventional cells. In conventional assembly technologies, this loss is unavoidable; the thickness of the tabs cannot be increased for fear of adding mechanical stress, and the number of busbars cannot be increased due to cell shading, which already accounts for roughly 8% performance decrease.

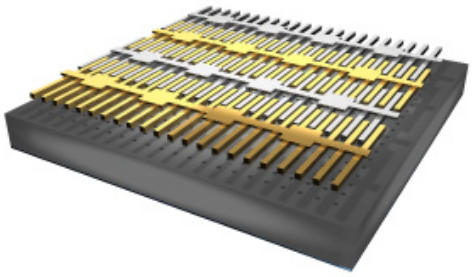
By contrast, the resistance of the interconnect for MMA is not constrained by front side metallization optical losses or by stress considerations. The combination of EWT with MMA results in less than half of the electrical interface performance loss compared to conventional module assembly. The Advent Solar Ventura™ architecture takes a system level approach to performance optimization, combining the strengths of the EWT cell architecture with the integrated backsheet MMA design to maximize energy output.



Comparison of Advent Solar EWT to conventional a PV cell. EWT moves gridlines from the front to the back of the cell, increasing power output and enabling MMA.

Consistent Output: In conventional module assembly technology, the process variability in the many assembly steps result in a wide range of module outputs. Standard modules require handling steps during tabbing, stringing, offloading, layup, and lamination stages. At each handling step, cells shift position; solder bonds are stressed and quality is compromised. Due to the many process steps, a wide variation builds up as the module is assembled. This variation manifests itself in a wide performance distribution and occasional expensive rework.

In contrast, Advent Solar Ventura architecture is designed for intelligent manufacturing methods. Cells are individually examined, softly handled and set into place in only a single step. This reduction of complexity in manufacturing results in highly repeatable, consistent module output.



Schematic view of an EWT cell using backside distributed contacts.

Reliability: Conventional tabber/stringers use heat intensive methods and create significant thermal stresses inside the module. These stresses are concentrated along the front busbars of the cells, and increase the likelihood of failures in the field.

In contrast, cells designed with Ventura Technology utilize distributed contacts—instead of few high stress bond locations, these cells use multiple bonds strategically distributed around the back of the cell—thus stress concentrations are evenly spread out over the area, resulting in improved reliability.

Aesthetics: Due to front-side metallization and inconsistent tolerances in strin ging technology, conventional modules are generally lacking in visual appeal.

In contrast, Ventura products are engineered to be beautiful by design. Striking, perfectly aligned clean blue squares of silicon represent a consumer product that customers are proud to showcase on homes and businesses.

Module using Advent Solar Ventura manufacturing.

Solar Green Index

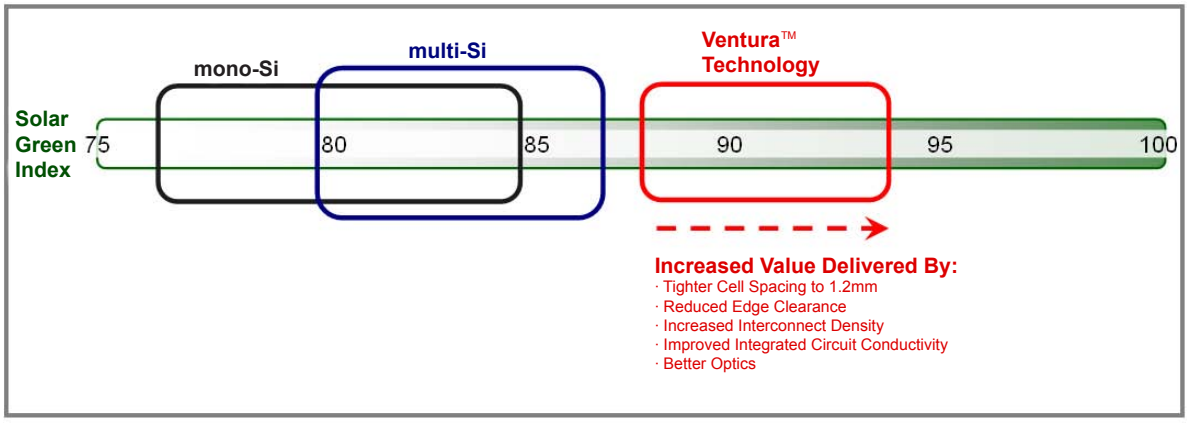
Advent Solar has developed the Solar Green Index, a measurable benchmark for assessing the efficiency and value of silicon PV architectures from a system perspective. One of the key factors in this index is the ratio of module efficiency to cell efficiency – the higher the index, the better the delivered value.

$$\text{Solar Green Index} = \frac{\text{Module Efficiency}}{\text{Cell Efficiency}} \times \text{Manufacturing Efficiency Factor}$$

Module Efficiency: This is arrived at by dividing module power by module area. Module efficiencies were computed from publicly available product specifications for each of the silicon PV technologies.

Cell Efficiency: Cell efficiencies were obtained by first determining the effective cell efficiency of a module—the minimum value required for a module to achieve the stated label power. The actual cell efficiency was calculated by using an encapsulated loss factor—a value of 4% for total encapsulated loss factor was used to describe conventional cells in this analysis. This is consistent with industry data [1]. Ventura technology has a much lower loss factor of only 1.2%

Manufacturing Efficiency Factor: This value represents the precision of module power given a consistent input of cells. Due to the precision and repeatability of Advent Solar's Ventura Technology, the Manufacturing Efficiency Factor is significantly improved over conventional technology. However, for simplification purposes the calculation performed below used 100% for all technologies.



The Solar Green Index. Calculations were performed by comparing the cell to module efficiency using published module specifications.

Peter Green, Advent Solar president and CEO, has challenged his company to lead the way in advancing the Solar Green Index. Advent Solar Ventura technology is the world's only comprehensive cell-to-module architecture designed from the ground up to help boost the Solar Green Index.

Conclusion

Advent Solar® Ventura™ Technology is based on a scalable architecture that squarely addresses the needs of the silicon PV market today and into the future. Conventional silicon PV manufacturing is approaching a gridlock in terms of scaling for cost and performance. This cannot be resolved without a system level architecture and a revolutionary approach to photovoltaic design and manufacturing. Advent Solar Ventura Technology delivers a unique, high value solution using proven semiconductor manufacturing techniques. The advanced EWT cell design eliminates front grid obstruction and improves light capture; it also enables an efficient planar module manufacturing process, MMA. The Ventura architecture optimizes cost, throughput and performance to deliver products with high energy output and reliability. The added advantage of aesthetics of Advent Solar modules reflects the excitement of Ventura Technology – Advent Solar: *Beautiful by Design*™

References

[1] A.W. Weeber et al., “How to achieve 17% cell efficiencies on large back-contacted mc-Si solar cells.” , 4th World Conference on PV Energy Conversion, Waikoloa, 2006