SUNPOWER
Smarter Solar™

White Paper:

SunPower Panels Generate the Highest Financial Return for Your Solar Investment

Summer 2008

Contents

Summary

SunPower manufactures the highest efficiency commercially available solar cells and solar panels. With average efficiency over 22 percent, our solar cells deliver up to 50% more power per unit area compared to conventional solar cells with efficiency of 14–15%, and two to three times the power of thin film products.[1]

This breakthrough technology was first commercialized in 2004 and since then has allowed our customers to significantly increase the amount of solar energy they can generate each year from a given roof area. Greater energy production means a better financial return and the increased satisfaction of a reduced carbon footprint.

In addition to higher sunlight-to-electricity conversion efficiency, SunPower technology also delivers better real-world solar performance compared with conventional solar power products.[2] This means that SunPower customers can expect to generate more electricity (kWh) over the course of a year compared with a conventional solar system of the same rated power (kW).

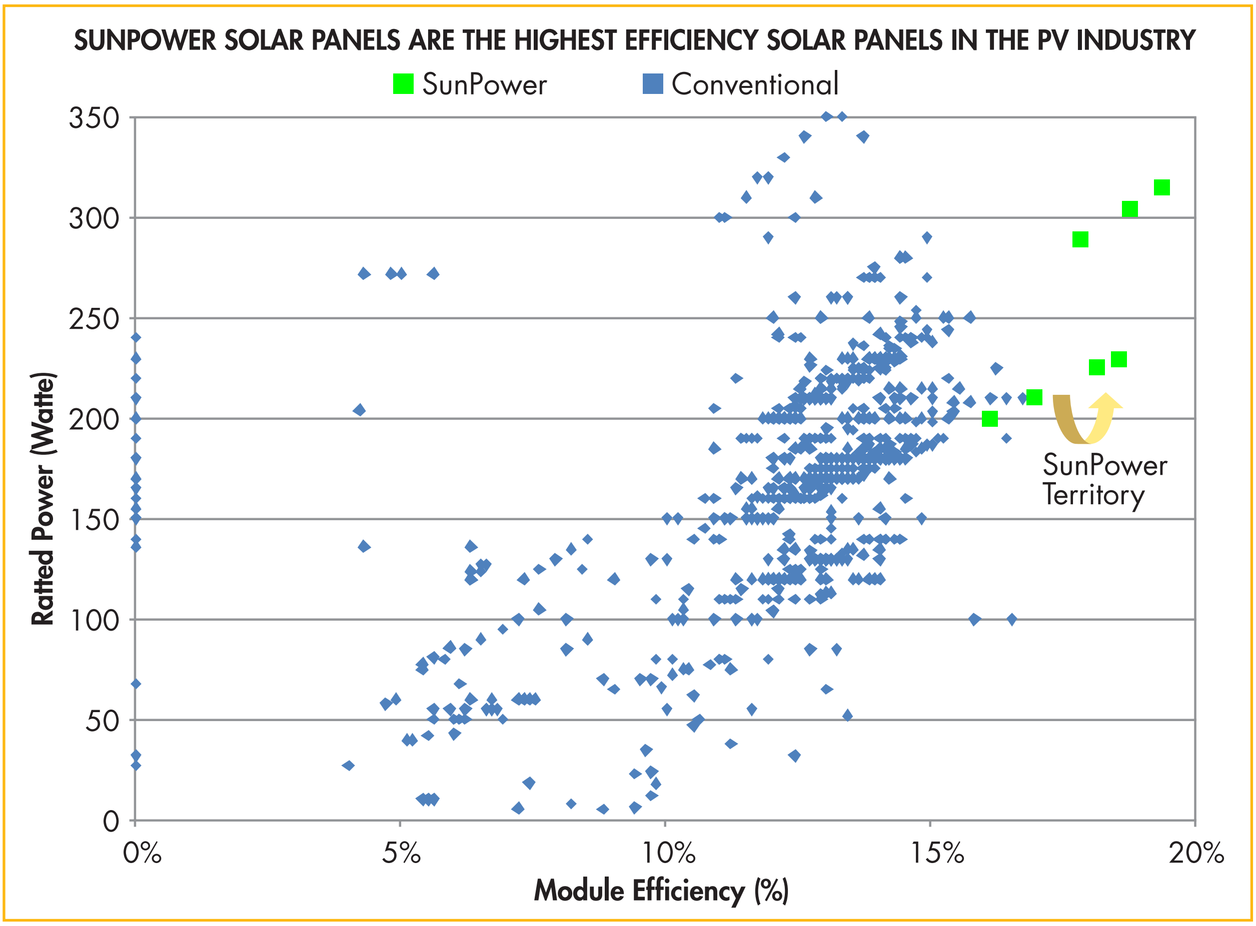
Why do SunPower panels perform better than conventional solar panels in field studies and tests? A combination of several key technological advancements enables SunPower panels to operate more efficiently at higher temperatures, at lower light intensity, and across a wide range of weather conditions.

SunPower's sleek all-black panel design is achieved by placing all of the electrical contacts and conductors on the back surface of the solar cells. Unlike conventional cells with shiny metallic contacts on the front surface, SunPower products have a unique, uniform aesthetic look and feel. SunPower panels are not only the smartest financial decision a customer can make – they also look better on the roof of a business or home.

Our industry-leading 10 year product warranty and 25 year limited output warranty combined with a highly-responsive and trained customer service organization and sustainable manufacturing practices make SunPower the first choice in solar power.

More Power through the Highest Panel Efficiency

Photon International's Annual Worldwide PV Market Survey illustrates that SunPower panels are the highest efficiency commercially available solar panels worldwide:



Source: **Photon International, Worldwide Market Survey, February 2008**

22% Efficiency Approaches Theoretical Maximum for Silicon Solar Cells

SunPower makes the world's most efficient solar cells at over 22 percent. But what happens to the other 78 percent of sunlight that is not captured by the SunPower solar cells?

To understand this, you need to know a little bit about sunlight and the photovoltaic effect. Sunlight is composed of light particles called photons. The solar spectrum consists of a wide range of photon energies, from high energy ultraviolet (UV) photons, to the medium energy visible photons (blue, green, yellow, red light), to lower energy near and far infrared photons. In a solar cell, photons are directly converted to electrons, which when in motion create current. The direct conversion of light to electricity is called the photovoltaic effect.

In general, one photon generates only one electron. Photons in the UV and visible range, comprising approximately 25% of the solar spectrum, have more energy than necessary to create an electron. This extra energy is lost as heat energy. Photons in the far infrared portion of the spectrum, comprising approximately 25% of the total, do not have enough energy to generate an electron. Since these photons are not absorbed, they generate no current. Last, an unavoidable loss of approximately 20% is due to fundamental physical processes. Therefore, the theoretical maximum efficiency of a silicon solar cell is approximately 29%. In mass-production, we expect the practical conversion efficiency limit to be approximately 24% to 25%.

Other energy conversion systems are far less efficient. Photosynthesis, for example, is only about 2% efficient at converting sunlight to plant matter. So, SunPower solar cells are about ten times more efficient than Mother Nature. And, plant matter may be converted into fuels, like alcohol or oil, and then burned to generate electricity, both with large efficiency losses. From this perspective, biofuels or fossil fuels are much less than 1% efficient in converting light to electricity.

Why SunPower Panels Are More Efficient

SunPower panels are the highest-efficiency panels in the solar PV industry for the following reasons:

- In most solar cells, numerous metal electrical contacts are placed on the front side in a fingered pattern. These "gridlines" are required to complete the electrical circuit and collect the solar electricity. But, wherever there is metal on the front of the solar cell, sunlight is blocked from entering the cell thereby creating shading loss. SunPower places all electrical contacts on the back of the solar cell, which eliminates shading loss from the front-side gridlines.

- Because there is no compromise from shading, we make the metal contacts on the back of our solar cells extra wide and thick to more easily conduct electrical current without the resistive losses common in conventional solar cells with very narrow and thin gridlines.

- We have exceptionally high quality manufacturing processes to both texture and apply an anti-reflective coating to the front surface of our cells. As a result, our cells capture more sunlight than conventional cells, which usually reflect a significant amount of solar energy away from the cell.

- In all solar cells, some electrons are lost before they reach the electrical contacts by a mechanism called 'recombination.' This reduces the amount of current and voltage generated by the solar cell. SunPower places a 'passivating' silicon dioxide coating on the front and rear surfaces of our cells, which minimizes the number of electrons lost by this mechanism.

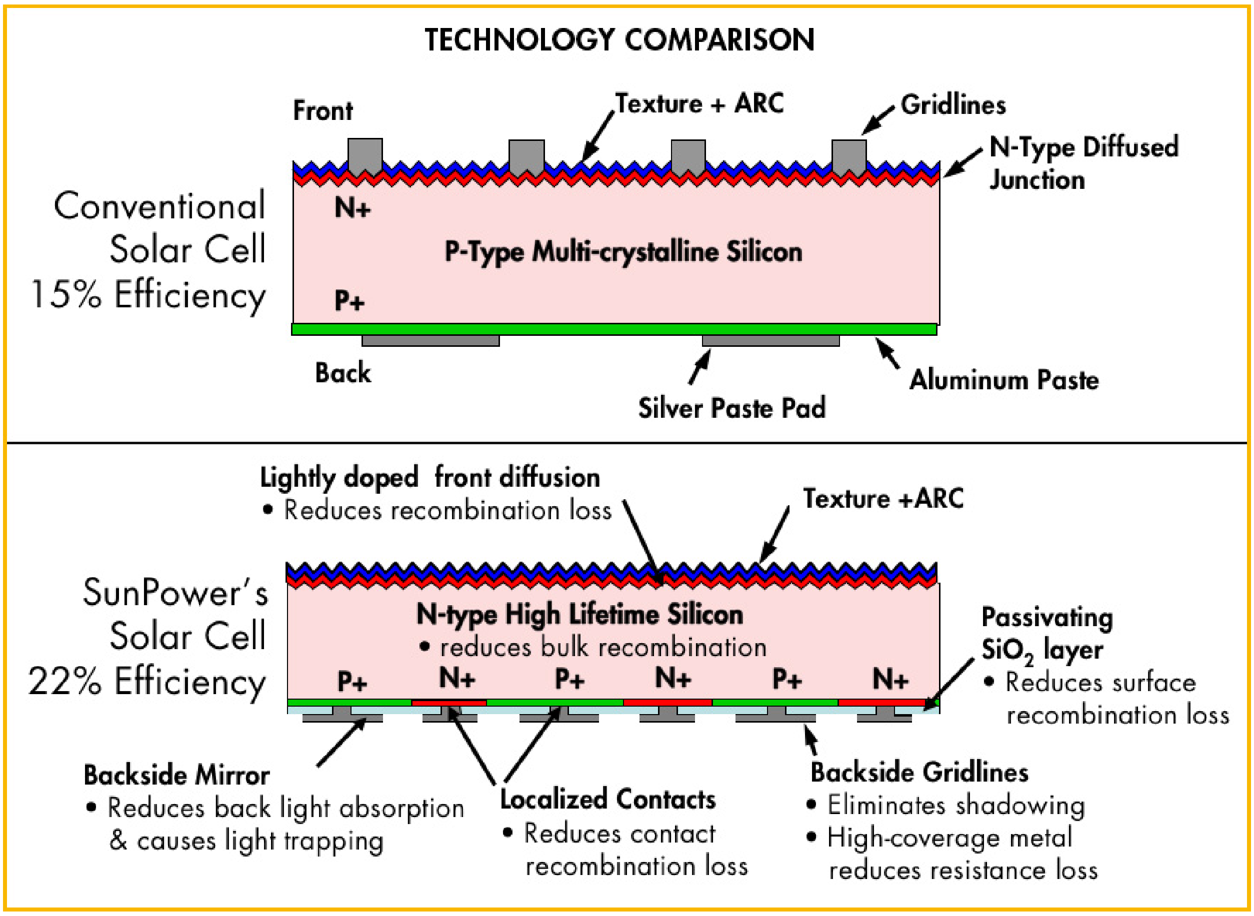
- The back side silicon dioxide layer, in combination with the back metal on top of the oxide, also creates a backside mirror that reflects sunlight that has not yet been absorbed back into the cell to produce more current.

- The electrical contact between the metallic gridlines and the silicon is made at small localized dots, which reduces the recombination loss that happens at silicon-metal interfaces.

- Most conventional solar cells are made from silicon wafers doped with boron atoms (p-type). When first exposed to sunlight, boron rapidly reacts with trace amounts of oxygen in the silicon to form a defect that degrades the performance of the solar cell.

The Institute for Solar Energy Research GmbH Hameln (ISFH) recently estimated that 'light-induced degradation' can result in as much as 2 to 7 percent reduction in the performance of conventional solar cells.[3] Because SunPower solar cells are made with boron-free n-type wafers, they are completely immune to this initial light induced degradation.

The following diagram illustrates the SunPower differences versus conventional solar cells:



Source: **SunPower Engineering**

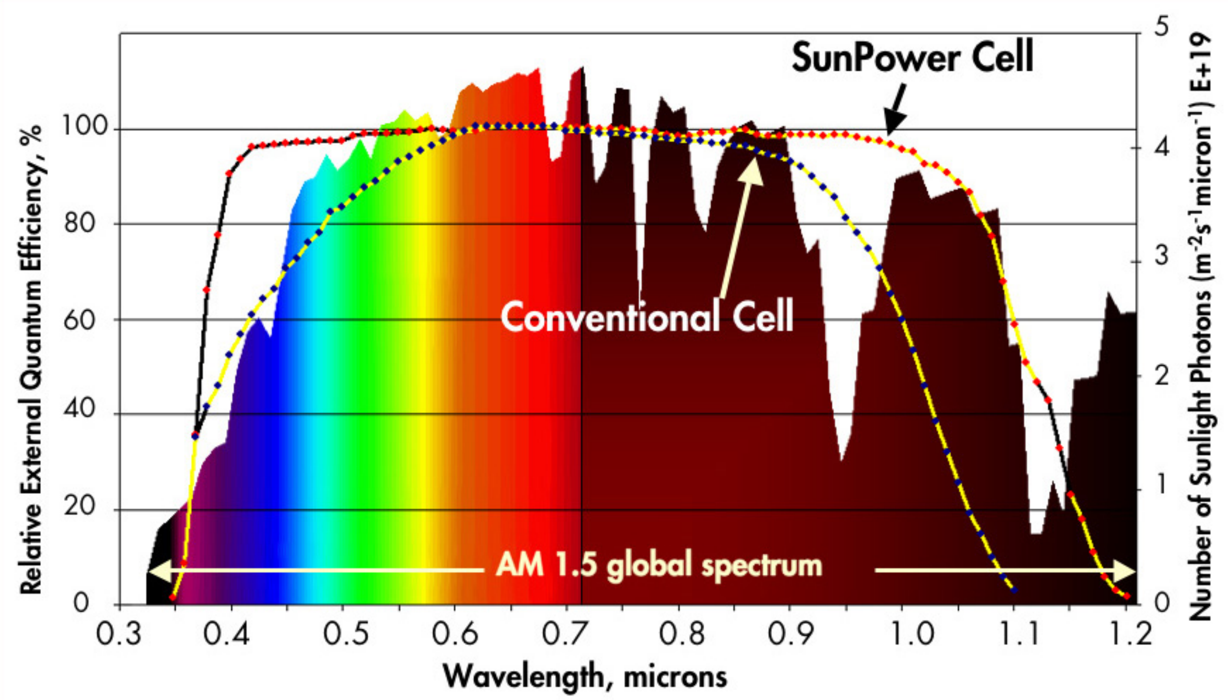
More Power through the Highest Panel Efficiency

Broader Light Spectrum Captured

SunPower panels are also designed to capture more sunlight through the following features:

- SunPower cells have a broader 'spectral response,' which means our solar cells convert more of the photons to electricity in the short wavelengths (blue) and long wavelengths (red) of the solar spectrum than conventional solar cells.
- SunPower enhances the short-wavelength (blue) response by improving the front surface passivation of our cells.
- Conventional cells usually require high concentration n-type dopants on the front surface, so that the metal can make good electrical contact to the silicon. Because SunPower cells have back-only contacts, we can optimize for passivation only. SunPower cells also have better long wavelength (infrared) response because our cells' superior internal optics.[4]

The following diagram illustrates how the SunPower solar cell response curve extends more into the blue and infrared areas of the light spectrum than conventional cells. Quantum efficiency is the probability that a photon at any given wavelength will be converted to an electron. SunPower's quantum efficiency is nearly 100% over a large range of the solar spectrum.



Source: **SunPower Engineering**

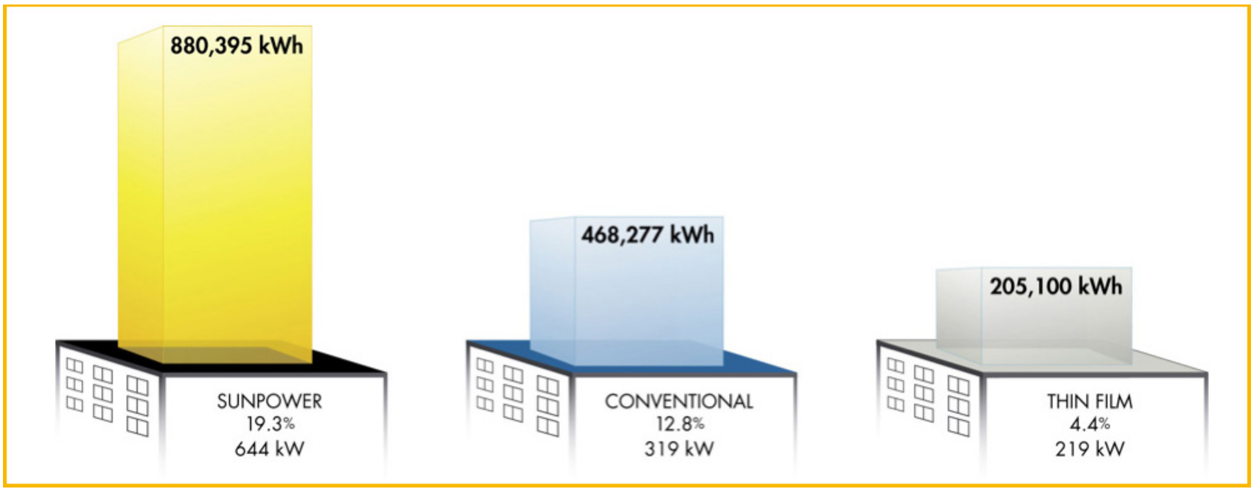
Why Panel Efficiency Is Important

Maximizing the efficiency of a PV panel is important because higher energy output per unit area (kilowatt-hours per square meter or kWh/m^2) increases the number of solar kWh generated.

High efficiency panels increase solar revenues in the following ways:

- Higher efficiency panels allow for larger capacity PV arrays to be mounted within the space-area constraints of a home or business.
- SunPower high efficiency panels mean our customers get a larger capacity system in a smaller space and have more room to optimize the orientation of the array. That means more solar kWh will be generated both annually and over the lifetime of the system.

The following diagram illustrates how SunPower panels, due to their high efficiency, enable a larger PV system that generates far greater solar kWh than both conventional and thin film solar panels on the same-sized commercial rooftop in the same location:



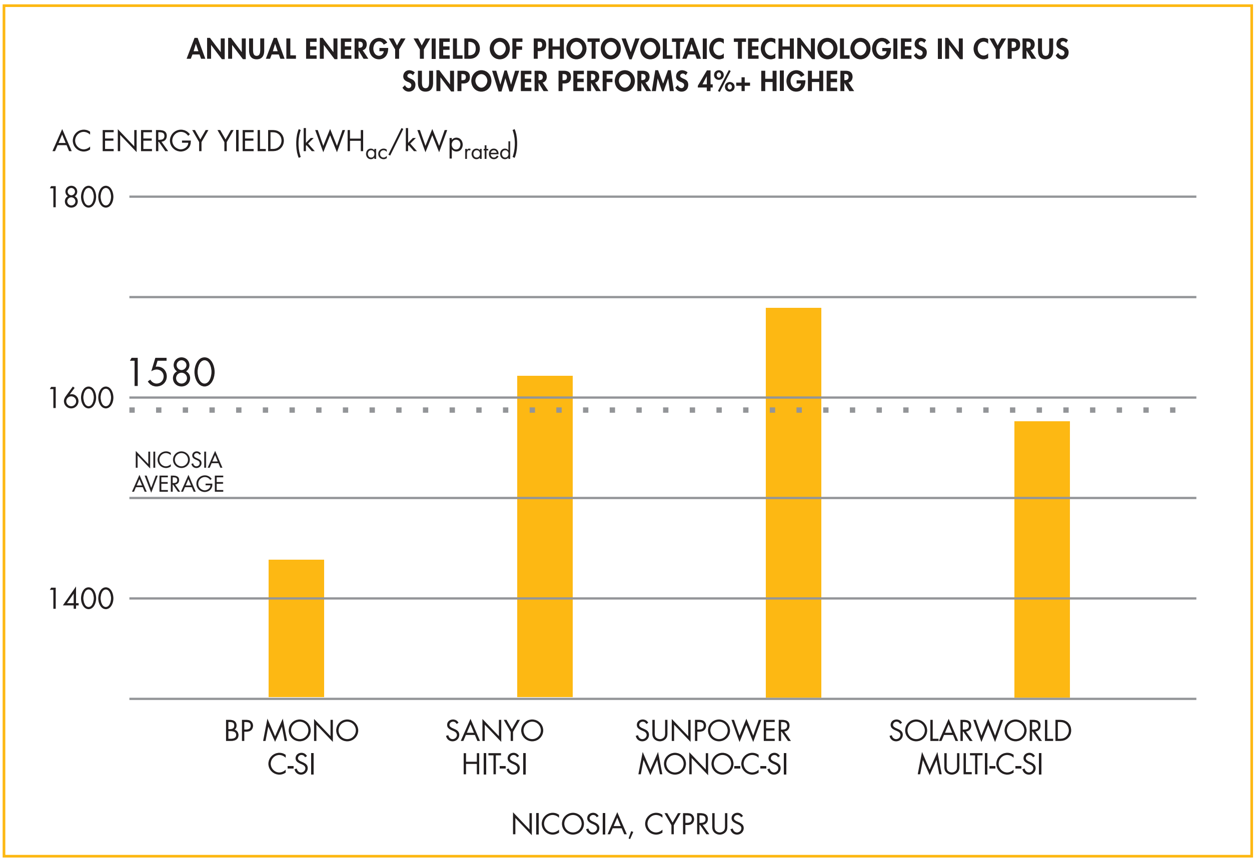
Source: SunPower PVGrid simulation in Rome, Italy. Fixed commercial roof size of 5,000 m^2

Better Performance Means More Energy per Rated Watt

SunPower panels are not only the highest efficiency solar panels commercially available, they also deliver more energy per rated watt than competing conventional solar panels.

That means that SunPower panels deliver more kWh per kW, generating more solar electricity in normalized conditions versus conventional solar panels and delivering an even greater return on your SunPower investment.

The following 3rd party university test demonstrates that SunPower generates from 4+% more energy per rated watt than alternative solar panels from leading industry competitors:



Source: **Department of Electrical and Computer Engineering, University of Cyprus & University of Stuttgart, 2006-2007,** http://www.ipe.uni-stuttgart.de

SunPower Panels Perform Better

SunPower panels deliver more energy per rated watt versus conventional solar panels for the following reasons:

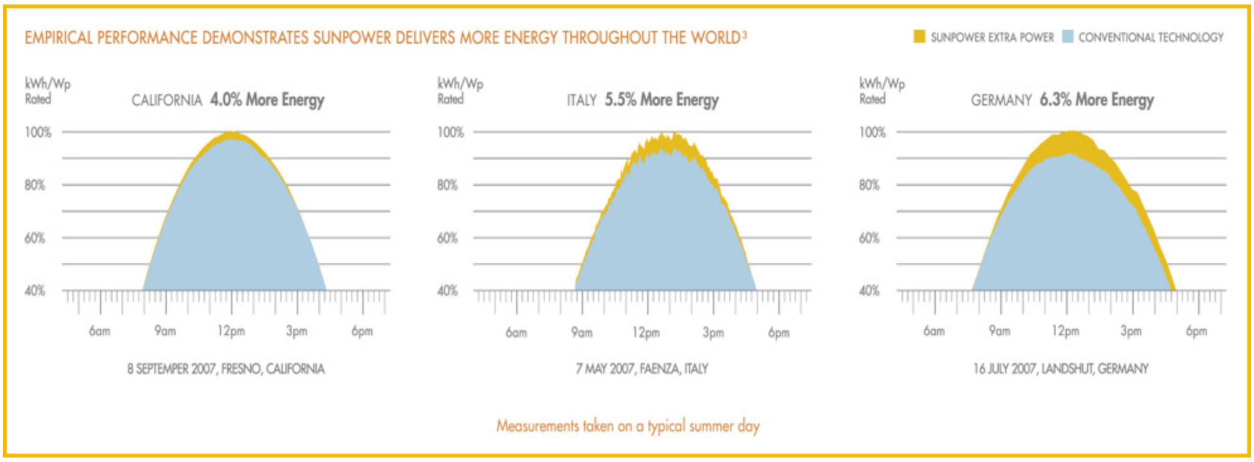
- SunPower panels offer superior high temperature performance compared with conventional PV systems. All solar cells get hot, and when they do, power production falls primarily due to a loss of voltage. SunPower cells drop in performance by roughly 0.38 percent per degree Celcius rather than the more typical 0.45 percent for conventional solar cells. Panels are generally tested at solar factories at 25 degrees C, but normally operate at about 45 degrees C in the field. At this temperature, SunPower panels can generate about 1.5% more energy per rated watt than conventional panels.

- SunPower panels avoid the 2-4 percent initial light-induced degradation commonly found with many solar panels. We maintain our industry-leading panel efficiencies over time.

- Our panels outperform conventional panels at low-light levels.

SunPower Performs Better Around the World

Below are empirical, side by side tests conducted by SunPower customers that show by how much SunPower panels outperform conventional solar panels on average summer days:



Source: SunPower Customers; comparisons at same site with identical inverters. System production output normalized to total solar panel factory test power.

Superior Quality and Manufacturing

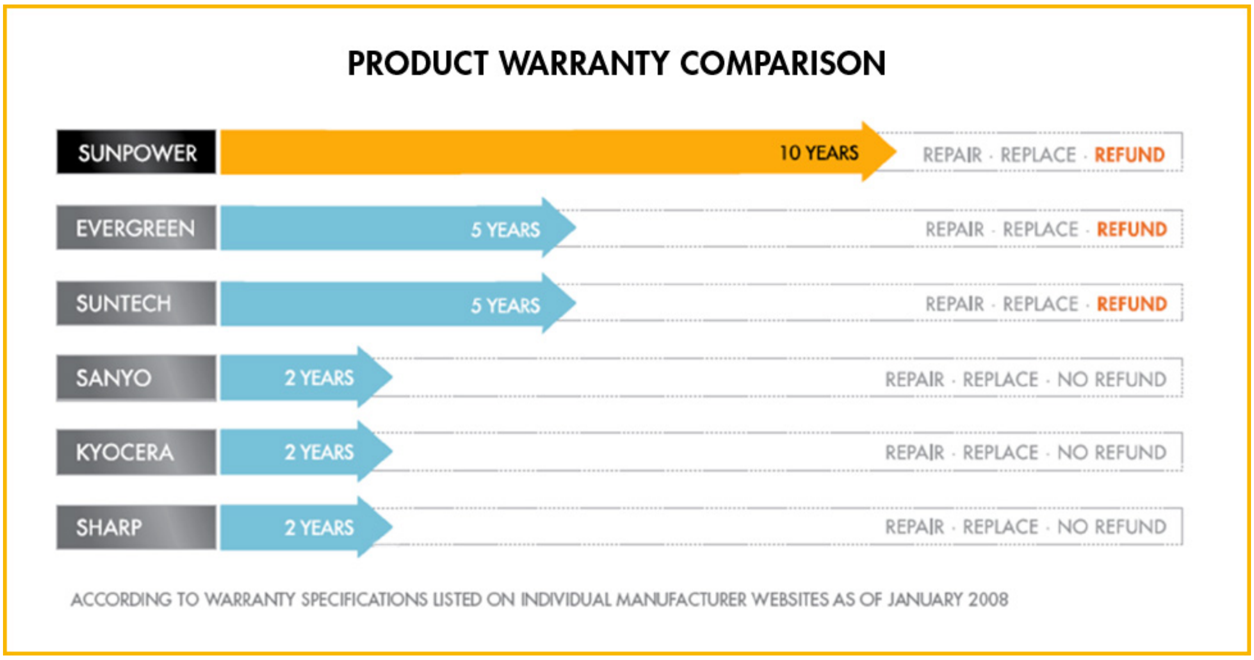
SunPower solar panels are UL (Underwriters Laboratories) listed and have been certified as meeting the requirements of the International Electrotechnical Commission (IEC) 61215, Edition 2, by the TUV Rheinland Group.

SunPower was the first solar panel manufacturer worldwide to qualify for and receive the new IEC 61730 safety standards certificate for its solar panels from TUV Rheinland Group. This certificate confirms that SunPower has met the stringent construction requirements set forth by the IEC certification board, in close cooperation with Underwriters Laboratories, to provide for the safe electrical and mechanical operation of its solar panels during their expected lifetime.

In addition, SunPower Corporation has been assessed and certified as meeting the requirements of ISO 9001:2000 for design, manufacturing, and sales of solar cells, panels, and optoelectronic devices, and sales of associated "balance of system" components.

SunPower Product Warranty

SunPower has the longest-lasting product warranty in the solar PV industry:



SunPower Refund at the discretion of SunPower.

The SunPower product warranty covers all parts and workmanship associated with the manufacture of SunPower solar panels. In addition, SunPower panels also carry a 25-year limited output warranty, which falls at the high end of the industry-standard 20-25 year limited output warranty time range.

Superior Quality and Manufacturing

SunPower warrants its panel output to 90% of Minimum Peak Power within the first 12 years following delivery and up to 80% of Minimum Peak Power for up to 25 years. All solar panels degrade over time, exclusive of initial light-induced degradation.

We are able to offer a superior warranty with confidence in both length of time and protection because we use only premium materials in the construction of all of our SunPower panels, ensuring decades of maintenance-free, high-quality performance.

Our commitment to advanced technology and adherence to the most stringent safety requirements for high-voltage operation ensure that our solar cells and panels are built to last.

Sustainable Manufacturing

SunPower has unique, differentiated, high quality manufacturing facilities where the emphasis on quality is a primary focus.

SunPower's manufacturing facilities in the Philippines were designed with environmental sustainability in mind. The most recent Fab 2 building was engineered with a variety of energy efficiency features that will help increase operations efficiency and cut energy costs.

These features include:

- Improved heating, ventilation, and air conditioning (HVAC) systems that significantly reduce the carbon footprint for a facility of this size and type.

- 100 percent of the hot water heating capacity generated by heat recovery air compressors.

- Cooling system efficiency that uses approximately 40 percent less electricity compared to typical systems in the Manila area.

- Improved, high-efficiency lighting that is 50 to 60 percent more efficient than standard lighting systems. To reduce electrical usage, SunPower uses 12-watt LED lighting that will last for approximately 10 years.

SunPower cells produce more watts per gram of silicon, which means our cells use less material to produce the same power. In addition, we use lead-free solder and release no toxic chemicals, all of which reduces the environmental impact of the manufacturing process.

Superior Quality and Manufacturing

Source: **SunPower Fab 2, Philippines**

"Fab 2 enables us to manufacture the world's highest-efficiency solar cells while reducing the carbon footprint by 50 percent compared to other buildings of this size," said Tom Werner, chief executive officer of SunPower Corporation.

In sum, SunPower delivers more solar energy to our customers and we do with sustainable and high quality manufacturing processes. That means a greater financial return on your investment and the knowledge that you are partnering with the industry's highest quality, most technologically-advanced solar systems provider.

References

1. Photon International, February 208, p134-161

2. Department of Electrical and Computer Engineering, University of Cyprus & University of Stuttgart, 2006-2007, http://www.ipe.uni-stuttgart.de

3. *"Characterization of iron-boron pairs in silicon ," The Institute for Solar Energy Research GmbH Hameln, http://www.isfh.de/institut_solarforschung/eisen-bor-paare_1.php?_l=1 & A Call for Quality, Power loss from crystalline module degradation,* Photon Magazine, Ines Rutschmann, March 2008, p106-11.

4. *Manufacture of Solar Cells with 21 percent Efficiency*, William P. Mulligan, Doug H. Rose, Michael J. Cudzinovic, Denis M. De Ceuster, Keith R. McIntosh, David D. Smith, and Richard M.Swanson, SunPower Corporation, June 2004.

5. www1.eere.energy.gov/solar/solar_glossary.html & SunPower definitions

Glossary[5]

Anti-Reflection Coating. A thin coating of a material applied to a solar cell surface that reduces the light reflection and increases light transmission.

Balance of System. All components and costs other than the photovoltaic modules/array, including design costs, land, site preparation, system installation, support structures, power conditioning, etc.

Band Gap. In a semiconductor, the energy difference between the highest valence band and the lowest conduction band.

Conduction Band (or conduction level). An energy band in a semiconductor in which electrons can move freely in a solid, producing a net transport of charge.

Dopant. A chemical element (impurity) added in small amounts to an otherwise pure semiconductor material to modify the electrical properties of the material. An n-dopant introduces more electrons. A p-dopant creates electron vacancies (holes).

Doping. The addition of dopants to a semiconductor.

Frequency. The number of repetitions per unit time of a complete waveform, expressed in Hertz (Hz).

Hole. The vacancy where an electron would normally exist in a solid. Holes behave like positively charged particles.

Intrinsic Layer. A layer of semiconductor material, used in a photovoltaic device, whose properties are essentially those of the pure, undoped, material.

Light Trapping. The trapping of light inside a solar cell by refracting and reflecting the light at critical angles. Trapped light will travel further in the material, greatly increasing the probability of absorption and hence of producing charge carriers.

Minimum Peak Power. Peak power minus the Peak power tolerance (as specified in SunPower's Product datasheet). "Peak power" is the power in peak watts that a PV module generates at STC (Standard Test conditions: Irradiance of 1000 W/m2, light spectrum AM 1.5g and a cell temperature of 25 degrees C).

N-Type Silicon. Silicon material that has been doped with a material that has more electrons in its atomic structure than does silicon.

Nominal Operating Cell Temperature (NOCT). The estimated temperature of a photovoltaic panel when operating under 800 W/m^2 irradiance, 20ºC ambient temperature and wind speed of 1 meter per second. NOCT is used to estimate module power output in its working environment.

Open-Circuit Voltage (V_{oc}). The maximum possible voltage across a photovoltaic cell. The voltage across the cell in sunlight when no current is flowing.

Glossary

Passivation. A chemical reaction that eliminates the detrimental effect of electrically reactive atoms on a solar cell's surface.

Peak Watt. A unit used to rate the performance of solar cells, panels, or arrays. The maximum nominal output of a photovoltaic device, in watts (Wp) under standardized test conditions, usually 1000 watts per square meter of sunlight with other conditions, such as temperature, specified.

Photon. A particle of light that acts as an individual unit of energy.

P-Type Semiconductor. A semiconductor in which holes carry the current. Produced by doping an intrinsic semiconductor with an electron acceptor impurity (e.g., boron in silicon).

Semiconductor. Any material that has a limited capacity for conducting an electric current. Certain semiconductors, including silicon, gallium arsenide, copper indium diselenide, and cadmium telluride, are uniquely suited to the photovoltaic conversion process.

Short-Circuit Current (Isc). The current flowing freely through an external circuit that has no load or resistance. The maximum current possible.

Recombination. The action of a free electron falling back into a hole (see definition above). Recombination can take place in the bulk of the semiconductor, at the surfaces, in the junction region, at defects, or between interfaces, and can result in recombination losses that reduce efficiency.

Valence Band. The highest energy band in a semiconductor that can be filled with electrons.

Wafer. A thin sheet of semiconductor (photovoltaic material) made by cutting it from a single crystal or ingot.

List of Acronyms

AR	Anti-reflective
HVAC	Heating, ventilation, and air conditioning
IEC	International Electrotechnical Commission
Isc	Short-circuit current
kW	kilowatt
kWh	kilowatt-hour
LED	Light-emitting diode
LID	Light-induced degradation
NOCT	Nominal operating cell temperature
PV	Photovoltaic
SiO_2	Silicon dioxide
UL	Underwriters Laboratories
V_{oc}	Open-circuit voltage
Wp	Peak watts

www.sunpowercorp.com