SunPower Cell and Module Technology:
Overview and Advantages

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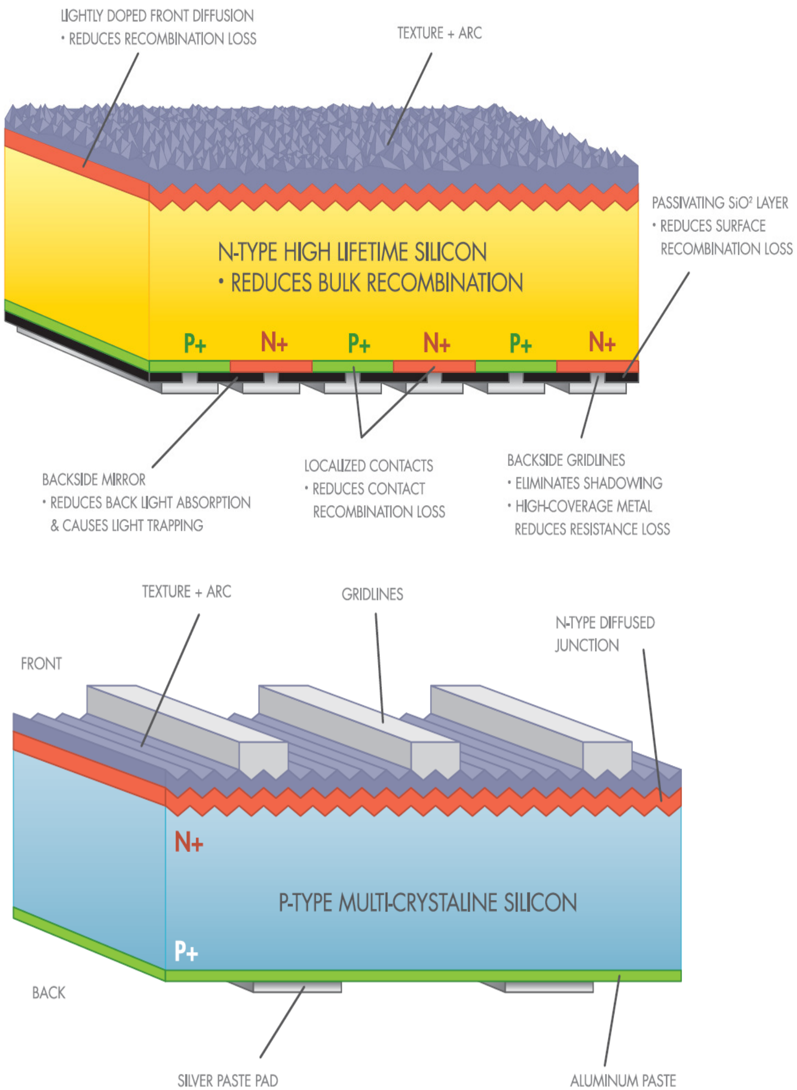
May, 2009

SunPower - A Differentiated Technology

- Highest Efficiency Cells and Modules
- Best Energy Performance (kWh/kWp)
- Solid Reliability & Quality

The Planet's
Most Powerful Solar

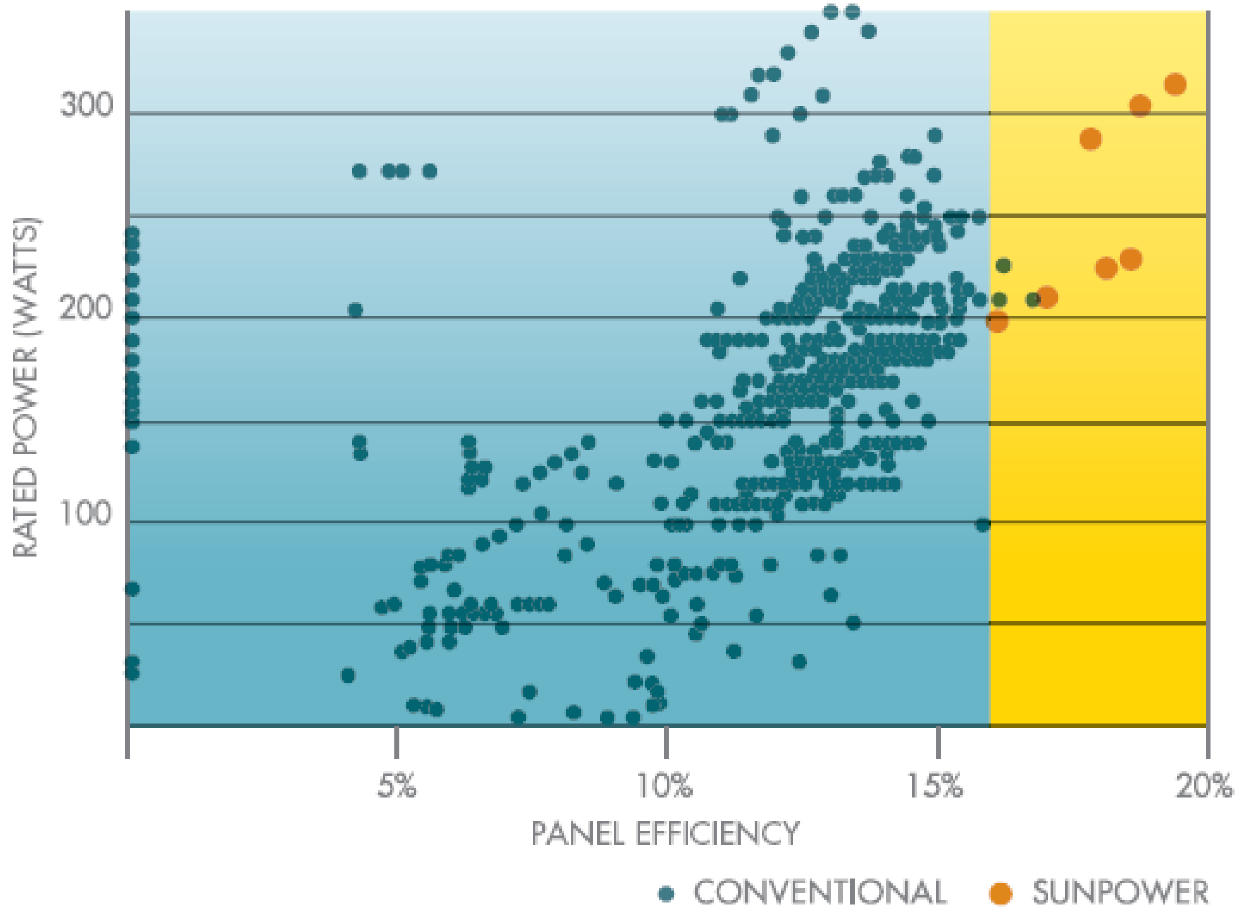
How SunPower Cells Achieve Record Efficiencies



1. **Maximum light capture**
   – Up to10% more sunlight on front surface
2. **Reduced Resistive losses**
   – Back contacts enable wider and thicker, lower resistance contacts
3. **Minimum Recombination Loss**
   – Passivating Silicon dioxide on front and back of cell minimizes recombination loss
4. **Maximum Absorption of Light**
   – Back-side mirror gives photons a second chance to generate power

Go to Detail View

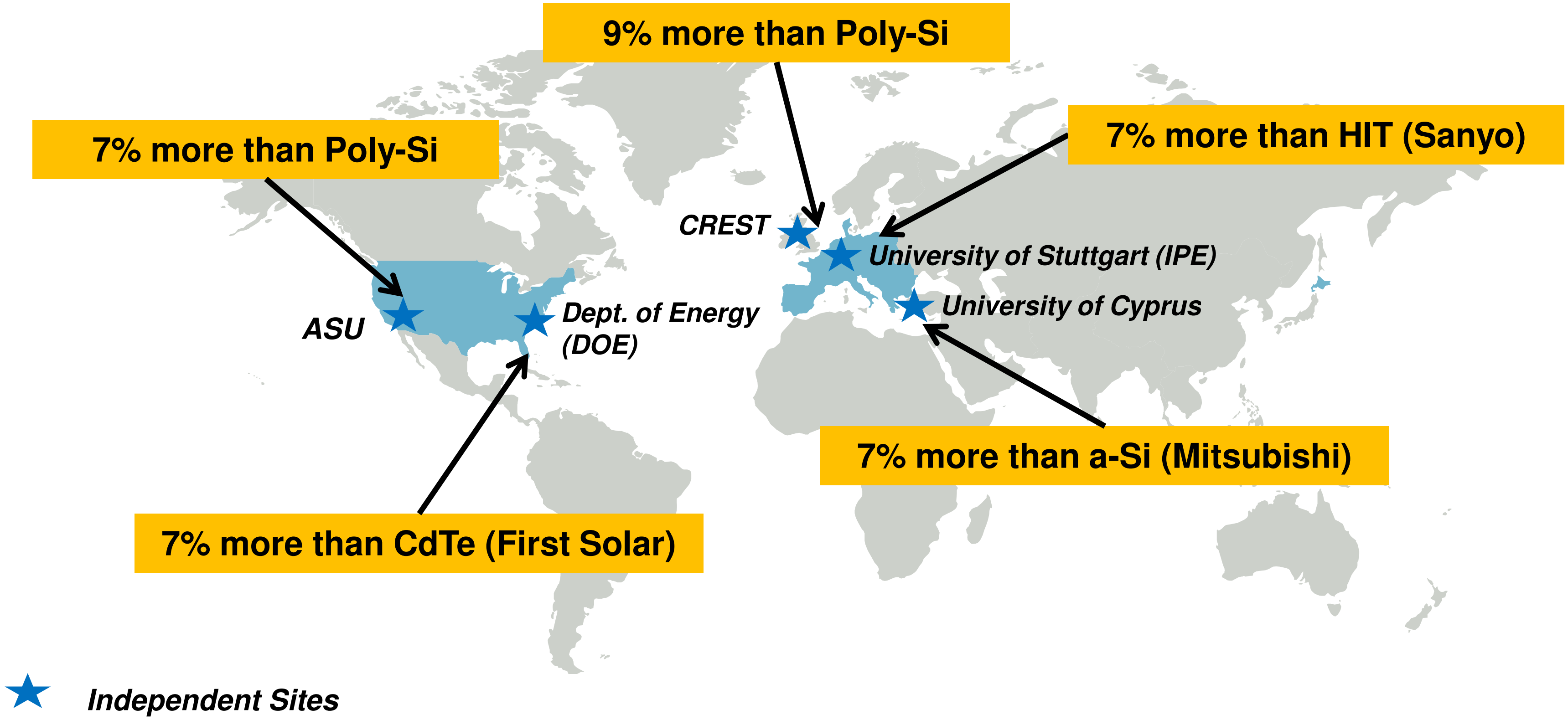
Highest **efficiency cells lead to the** ***highest*** **efficiency modules**



Photon International's Annual Worldwide PV Market Survey, February, 2008.

Best Energy Performance

Independent tests show that SunPower modules provide the ***best*** energy performance (kWhs/kWp) at sites throughout the world

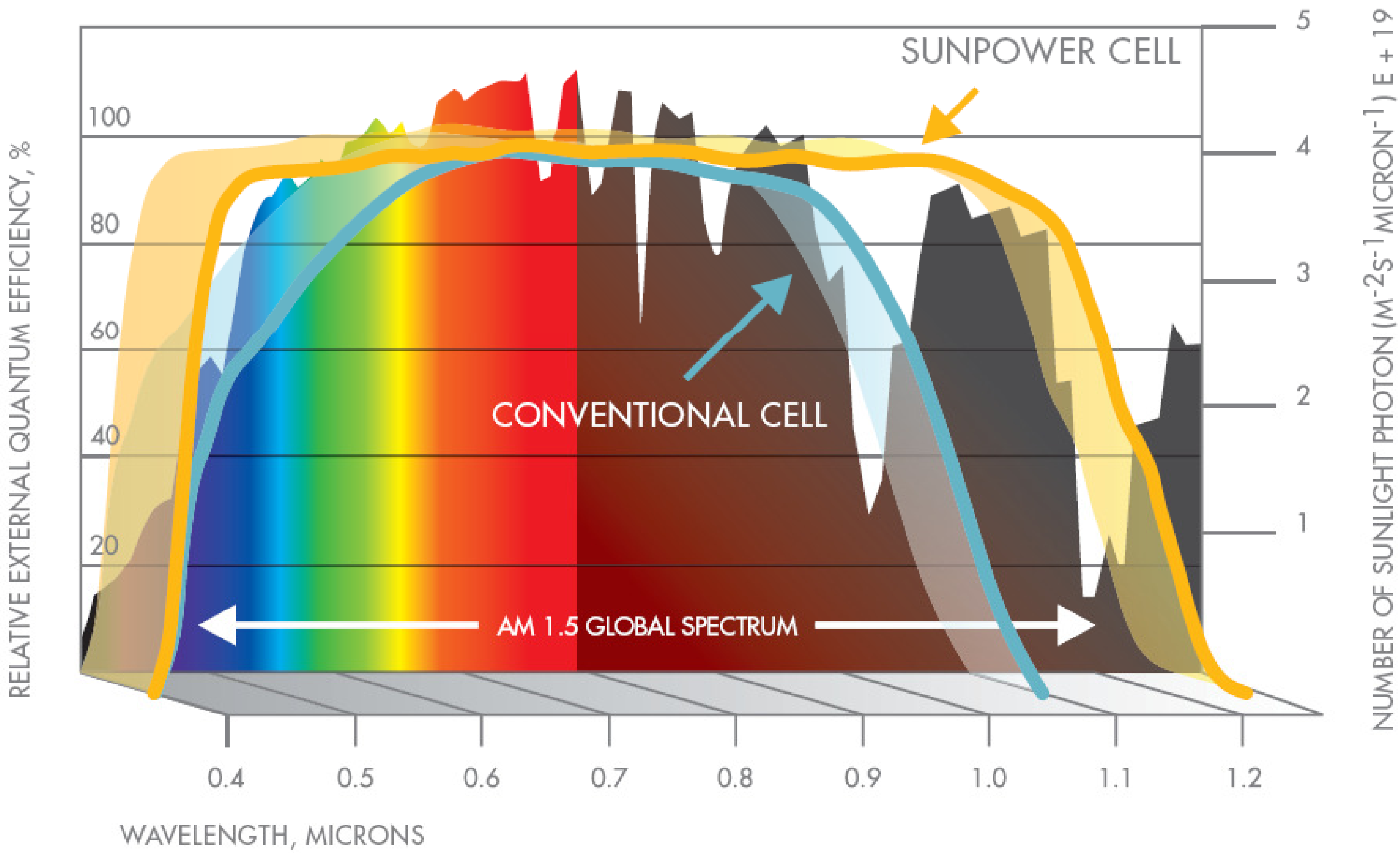


How SunPower Cells Produce *More Energy per Watt*

1. **Superior Light Capture**
   - Broader spectral response
   - Better low-light performance
2. **Higher Performance at Higher Temperatures**
   - Lower temperature coefficients than conventional crystalline
3. **No Light Induced Degradation (LID)**
   - SunPower cells does not suffer a initial ~3% degradation when first exposed to sunlight
4. **Higher Lifetime Energy Yield**
   - Studies show that crystalline modules degrade less year to year than thin film

Broad Spectral Response

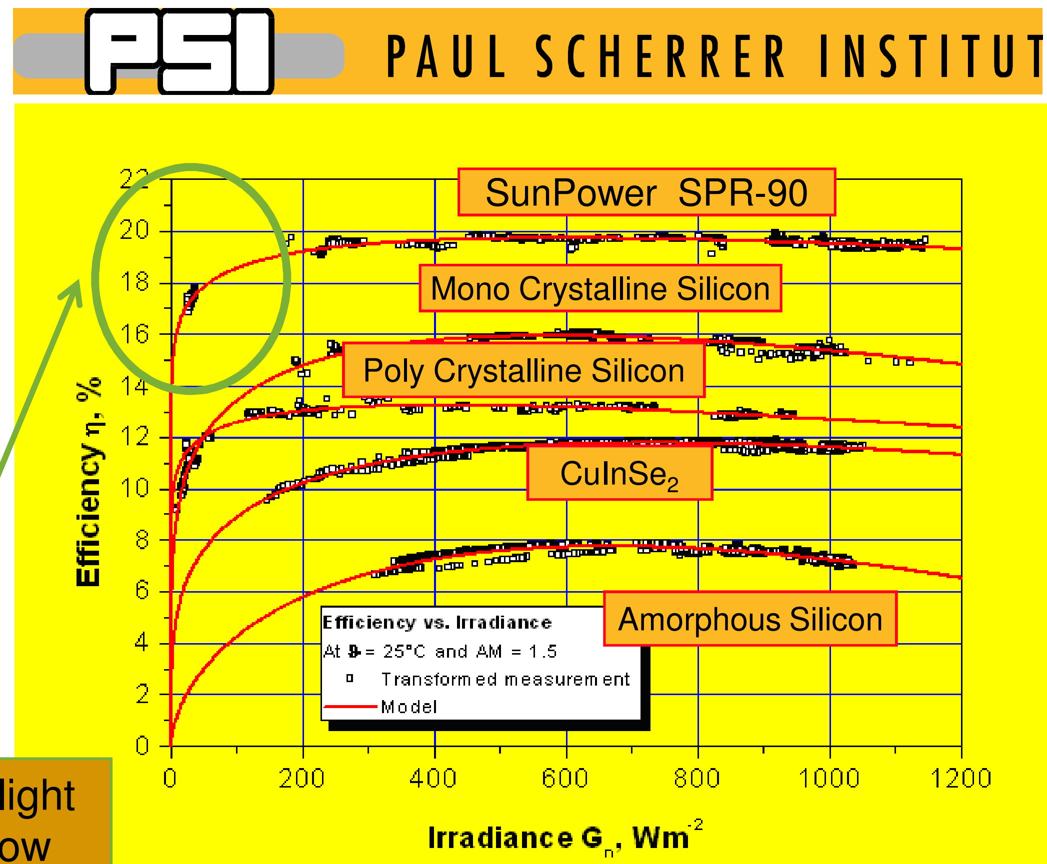
SunPower Cells capture more light from the blue and infra-red parts of the spectrum, enabling higher performance in overcast and low-light conditions



Better Low-Light Performance

SunPower solar cells generate more power at low light levels relative to other technologies

- Voltage builds rapidly at low insolation levels
- Better performance in overcast conditions
- Inverter wakes up earlier and runs later



Sharper knee of curve at low light levels is indicative of better low light performance

Higher Performance at Higher Temperatures

Due to lower temperature coefficients and lower normal cell operating temperatures (NOCT), SunPower panels generate more energy at higher temperatures compared to standard c-Si modules

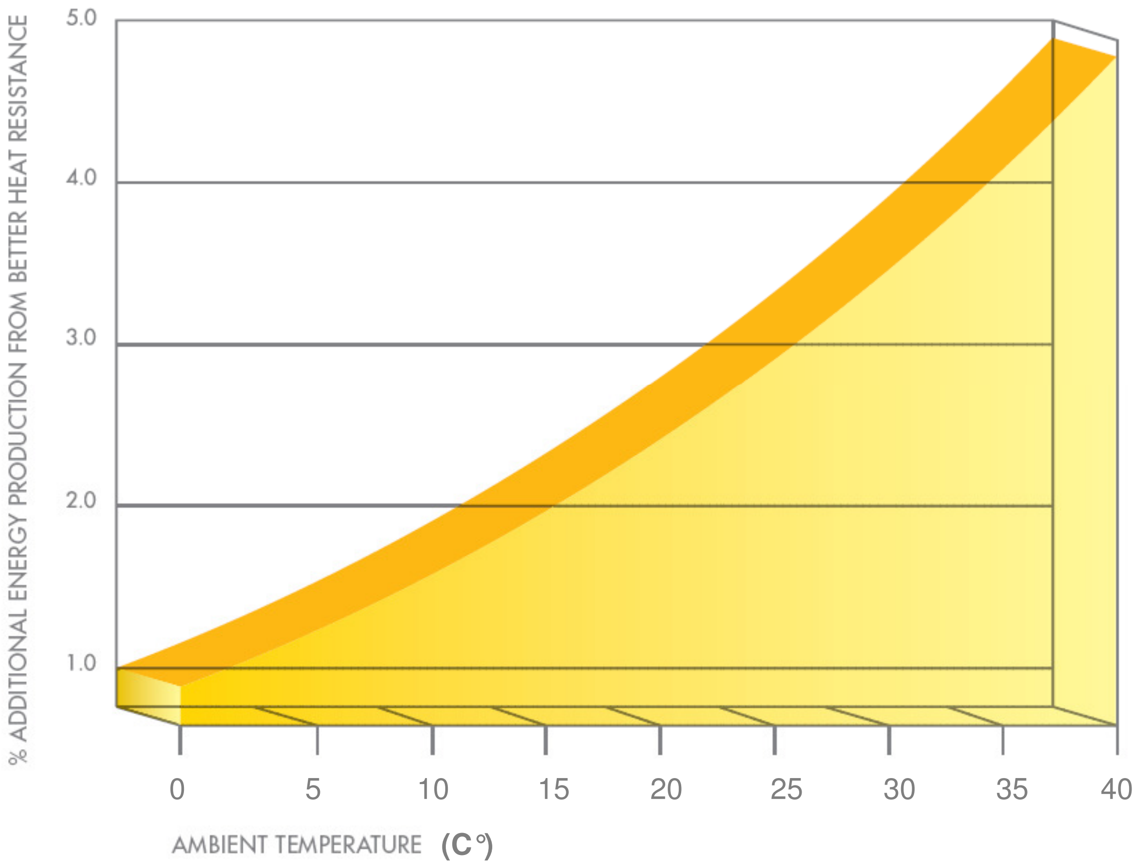
<u>Temp Coefficient:</u>

SunPower	-0.38% / ℃
Std c-Si	-0.47% / ℃

<u>NOCT:</u>

SunPower	45 ℃ +/-2
Std c-Si	47 ℃ +/-2

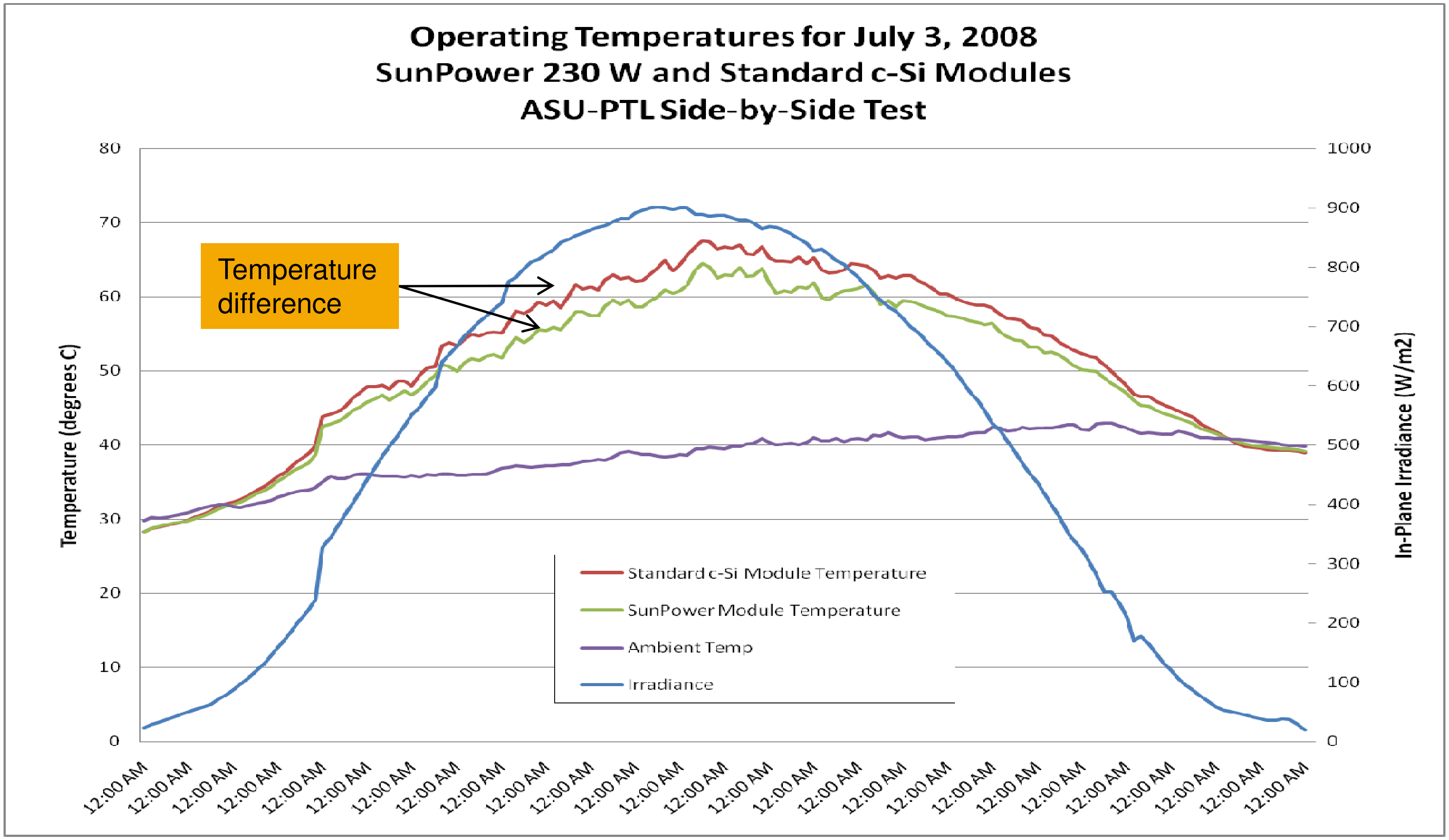
AS THE AMBIENT TEMPERATURE RISES, SUNPOWER'S ADVANTAGE INCREASES.



[2]NOCT is measured at continuous sunlight exposure of 800W/m2, 20°C ambient, and wind speed of 1m/second.

Operating Temperatures – SunPower vs. Standard c-Si

Higher efficiency modules operate at lower temperatures because they convert more of the sun's energy to electricity – lower efficiency modules convert it to heat instead



SUNPOWER™

No Light Induced Degradation (LID)

SunPower **n-type** solar cells are not subject to LID and do not lose 3% of initial power once exposed to sunlight like conventional **p-type** c-Si cells

PHOTON International March 2008

A call for quality

Power loss from crystalline module degradation causes a big headache for the industry

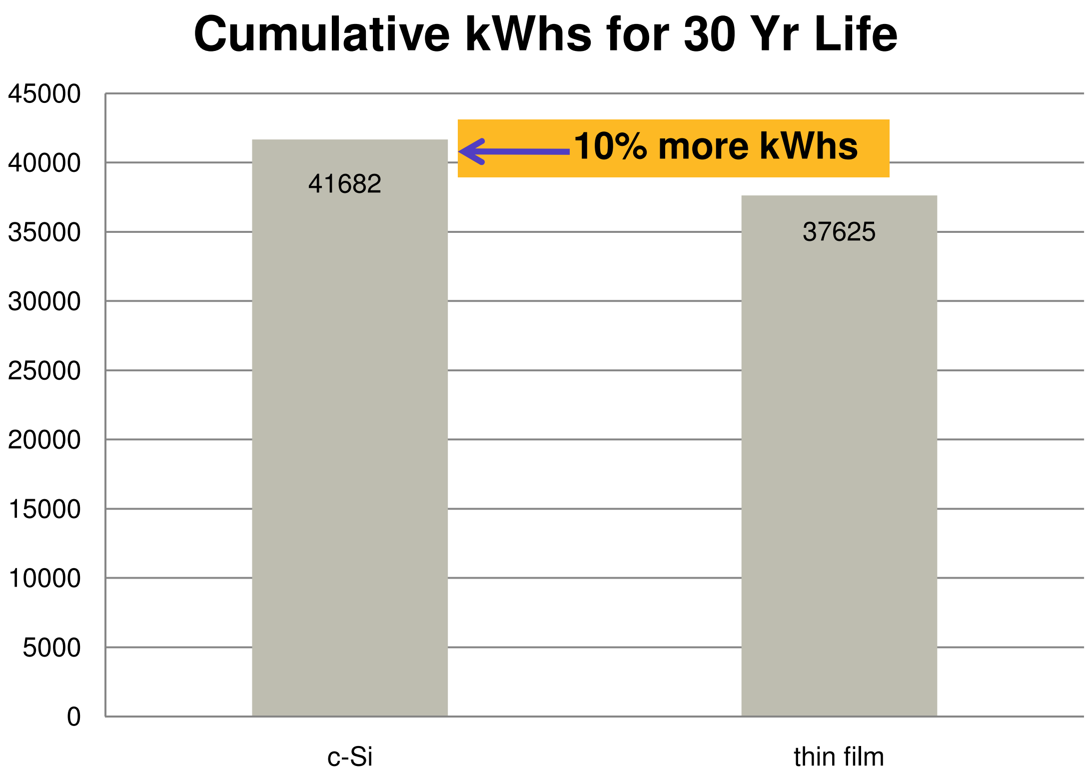
It's not just thin-film modules – crystalline solar cells are also subject to degradation. That's already well-known. But the magnitude of this unpleasant effect on monocrystalline products depends primarily on the composition of the silicon being used. Still, few manufacturers dare to say what has long been common knowledge: a lot of low quality silicon is being sold, and it's slipping through the quality control system used by cell and module manufacturers.

More Information

Access Article

Higher Lifetime Energy Yield

Studies by independent researchers show that crystalline technologies typically have lower expected year to year performance degradation than thin films.



Assumptions:

1) 1,500 kWh/kWp (1st year) for both technologies
2) Annual Degradation Rate from Osterwald Paper *(%/yr)
   - **- c-Si -0.53%**
   - **- Thin Film -1.27%**

*Degradation rates based on paper published by National Renewable Energy Laboratory (NREL), Golden, CO. Paper by C.R. Osterwald, "Comparison of Degradation Rates of Individual Modules held at Maximum Power"

Background on Degradation Rate Calculations

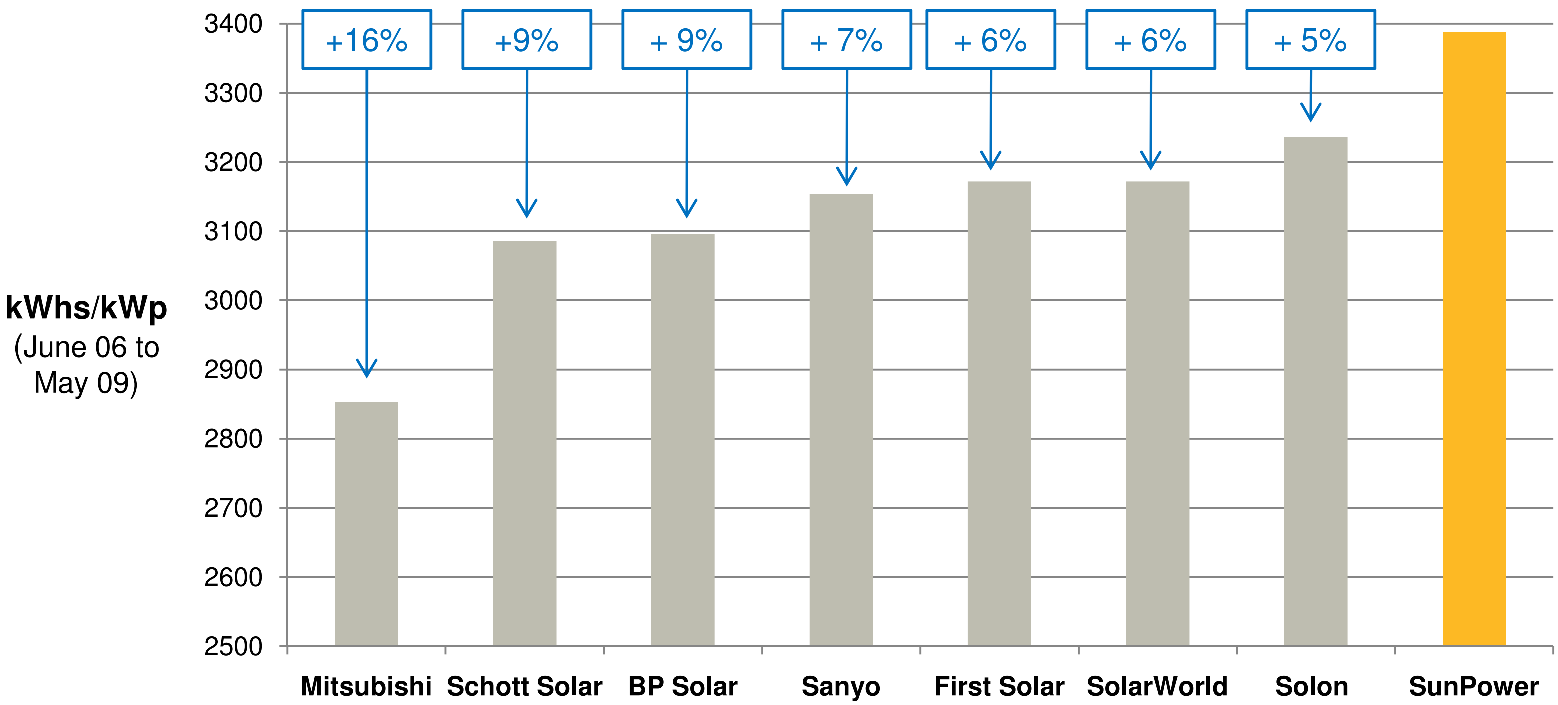
1. Degradation rates from NREL study include those measured at NREL over past 15 years and data from other papers published on this topic.
2. Calculations below based on data presented in study and used only data for modules measured 5 years or more

Technology	Degradation Rate (% per year)	# of modules measured	Average Years Measured	Total Years Measured	Comments
Crystalline	-0.53	13	8.26	116	Both x-Si, poly-Si
Thin Film	-1.27	10	8.12	106	Mostly a-Si, 2 CdTe, 1 CIS

Degradation rates based on paper published by National Renewable Energy Laboratory (NREL), Golden, CO. Paper by C.R. Osterwald, "Comparison of Degradation Rates of Individual Modules held at Maximum Power." See study.

University of Stuttgart (IPE) – Stuttgart, Germany

SunPower energy yield highest in on-going multi-year test when compared to high efficiency, conventional crystalline and thin film technologies



Technology:	(a-Si thin film)	(poly-Si)	(mono-Si)	(HIT-Si)	(CdTe thin film)	(poly-Si)	(poly-Si)	(back contact mono-Si)

Cumulative kWh yield (kWh ac / kWp rated) from June 2006 to May 2009 – Stuttgart, Germany

Source: Institut für Physikalische Elektronik (***ipe***) University of Stuttgart, Germany. Testing started in June 2006 and is on-going - Webpage: http://www.ipe.uni-stuttgart.de/index.php?lang=ger&pulldownID=12&ebene2ID=44. More information provided in appendix.

University of Cyprus (IPE) – Nicosia, Cyprus

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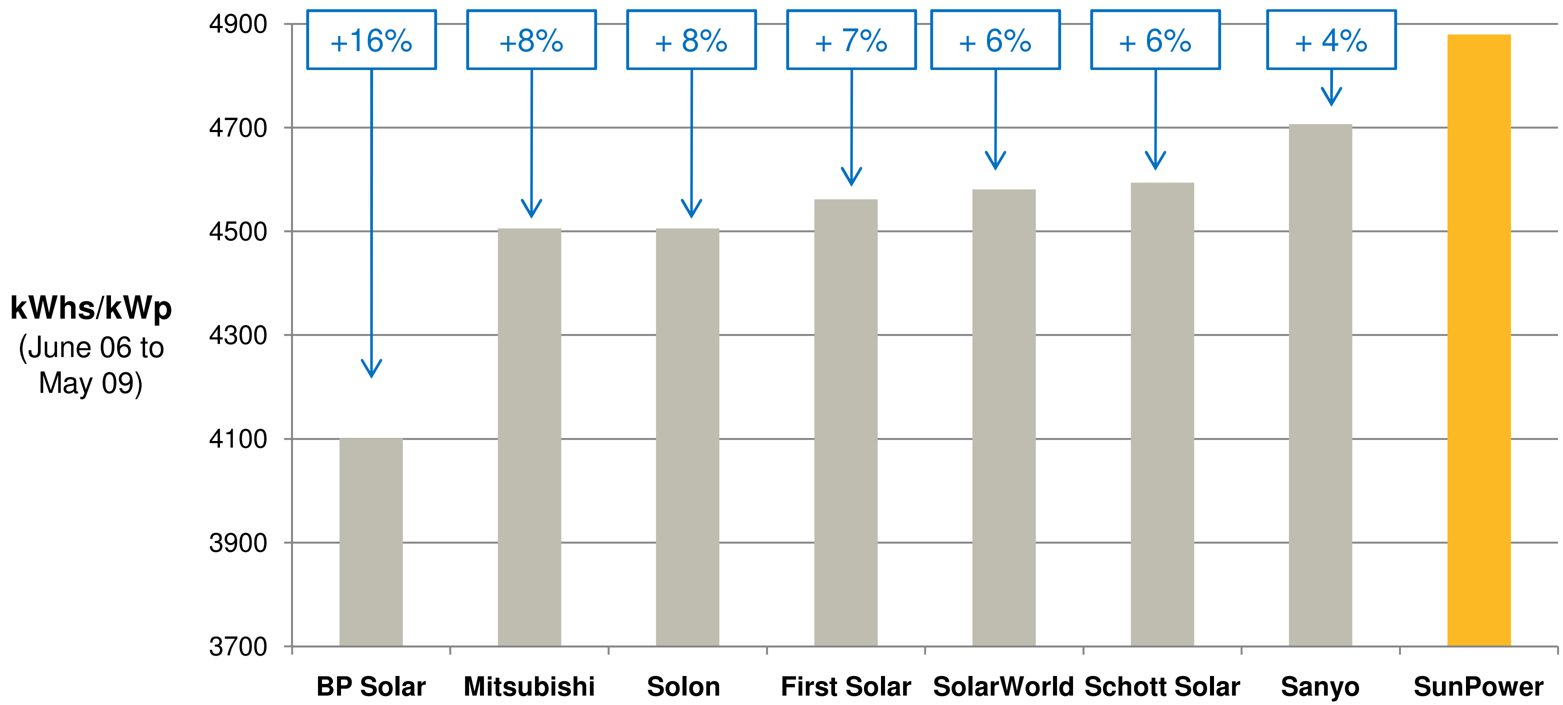


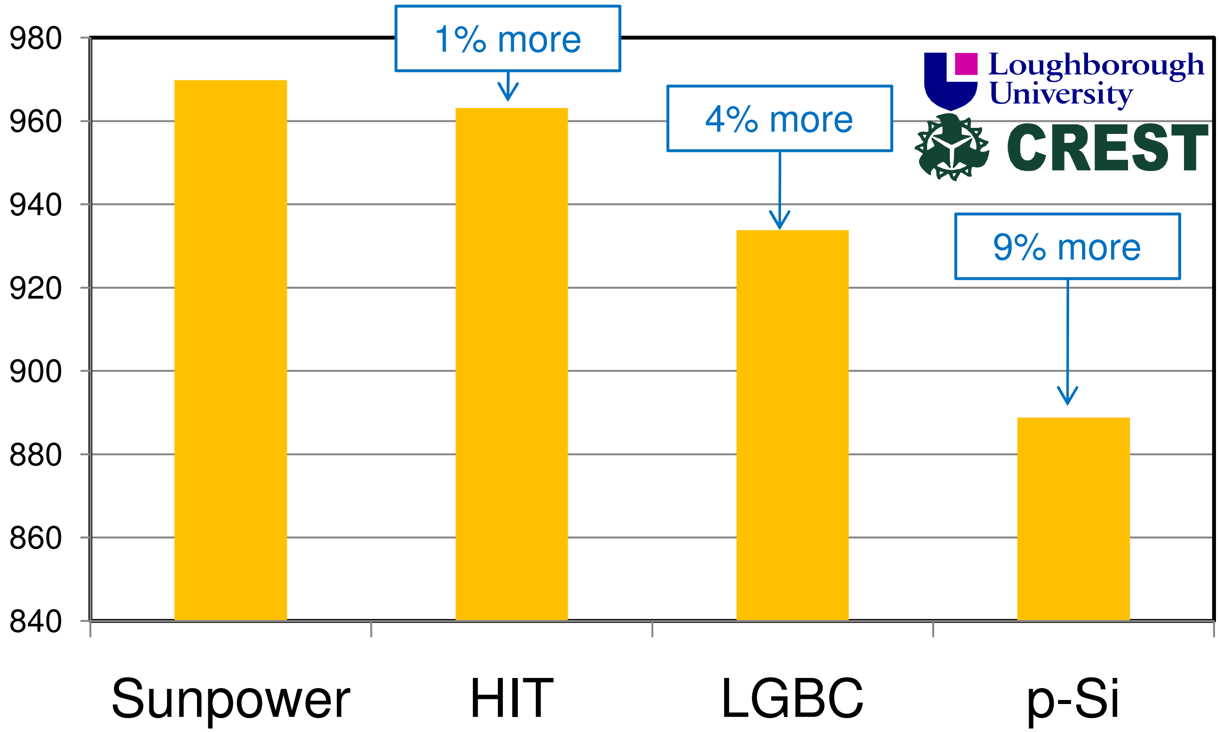
Technology:	*(mono-Si)*	*(a-Si thin film)*	*(poly-Si)*	*(CdTe thin film)*	*(poly-Si)*	*(poly-Si)*	*(HIT-Si)*	*(back contact mono-Si)*

Cumulative kWh yield (kWh ac / kWp rated) from June 2006 to May 2009 – Stuttgart, Germany

Source: Department of Electrical and Computer Engineering - University of Cyprus in Nicosia. Testing started in June 2006 and is on-going - Webpage: http://www.ipe.uni-stuttgart.de/index.php?lang=ger&pulldownID=12&ebene2ID=44. More information provided in appendix

Loughborough University / CREST Study - Leicestershire, UK

SunPower energy yield highest compared to high efficiency technologies and conventional crystalline in a *northern European* climate



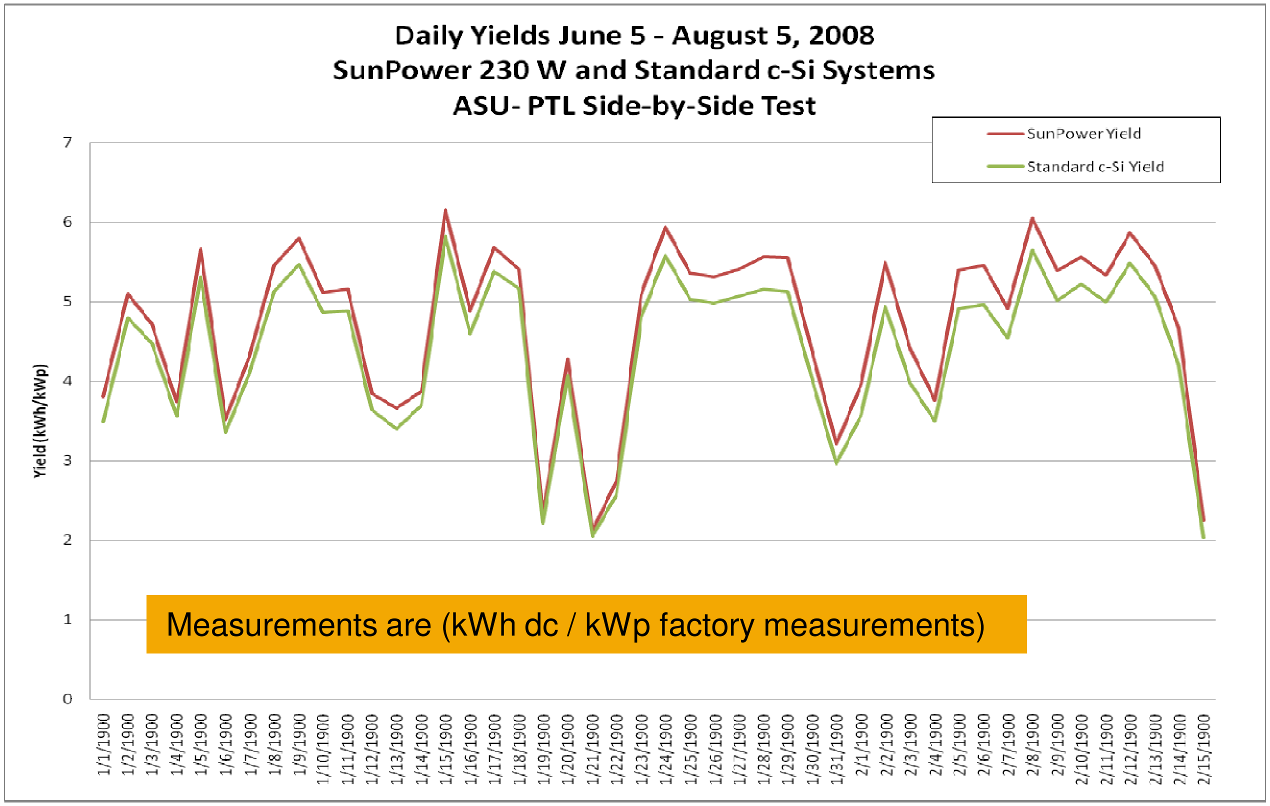
Specific energy yield (kWh ac / kWp measured) from April, 2007 to April 2008 – Leicestershire, UK

Source: Centre for Renewable Energy Systems Technology (CREST), University of Loughborough. Based on paper, titled "Performance of High-Efficiency PV Systems in a Maritime Climate" by Matthias Strobel, July, 2008

SunPower test conducted by ASU – Tempe, Arizona

SunPower energy yield higher compared to conventional crystalline technologies in a *high temperature desert* climate

7.2% higher energy yield than standard c-Si panels



Objective of ASU site monitoring:
Measure and quantify differences in performance between SunPower modules and Standard crystalline silicon (c-Si) modules using independently verifiable data at a high temperature site

Module Type	Modules	Capacity (Wp)
SunPower 225W	7	1555
Std c-Si 208 W	9	1871

ASU – Arizona State University is a well known independent lab in the US that specializes in PV testing and monitoring

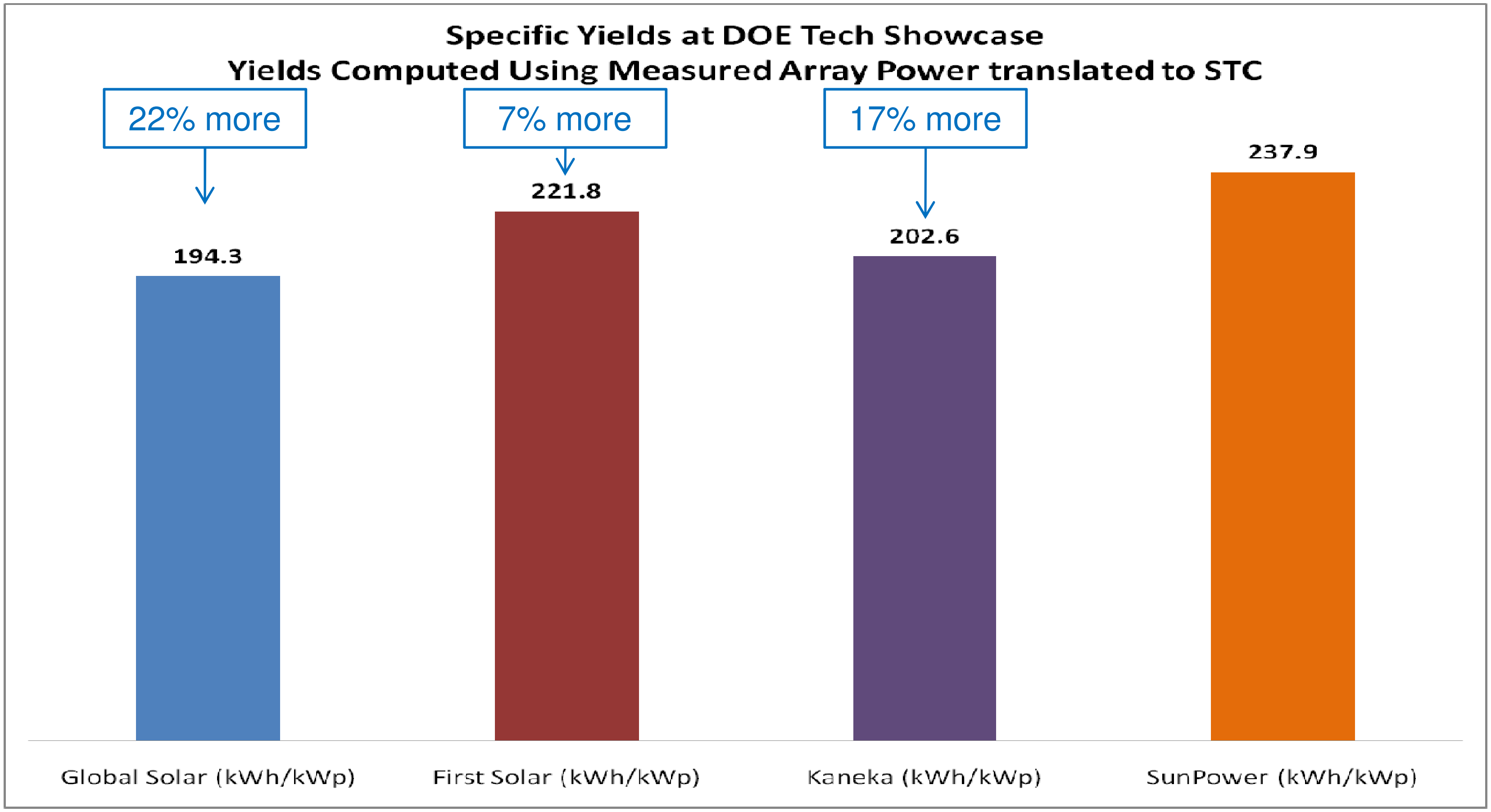
US Dept. of Energy Showcase Test Site – Washington, DC

US Dept. of Energy (DOE) has installed various new PV technologies on its roof to test relative energy performance between *high efficiency* and *thin film* technologies

SunPower (Back-Contact Mono) | Kaneka (a-Si) | First Solar (CdTe) | Global Solar (CIGS)

Dept of Energy Tech Showcase System – Initial Results

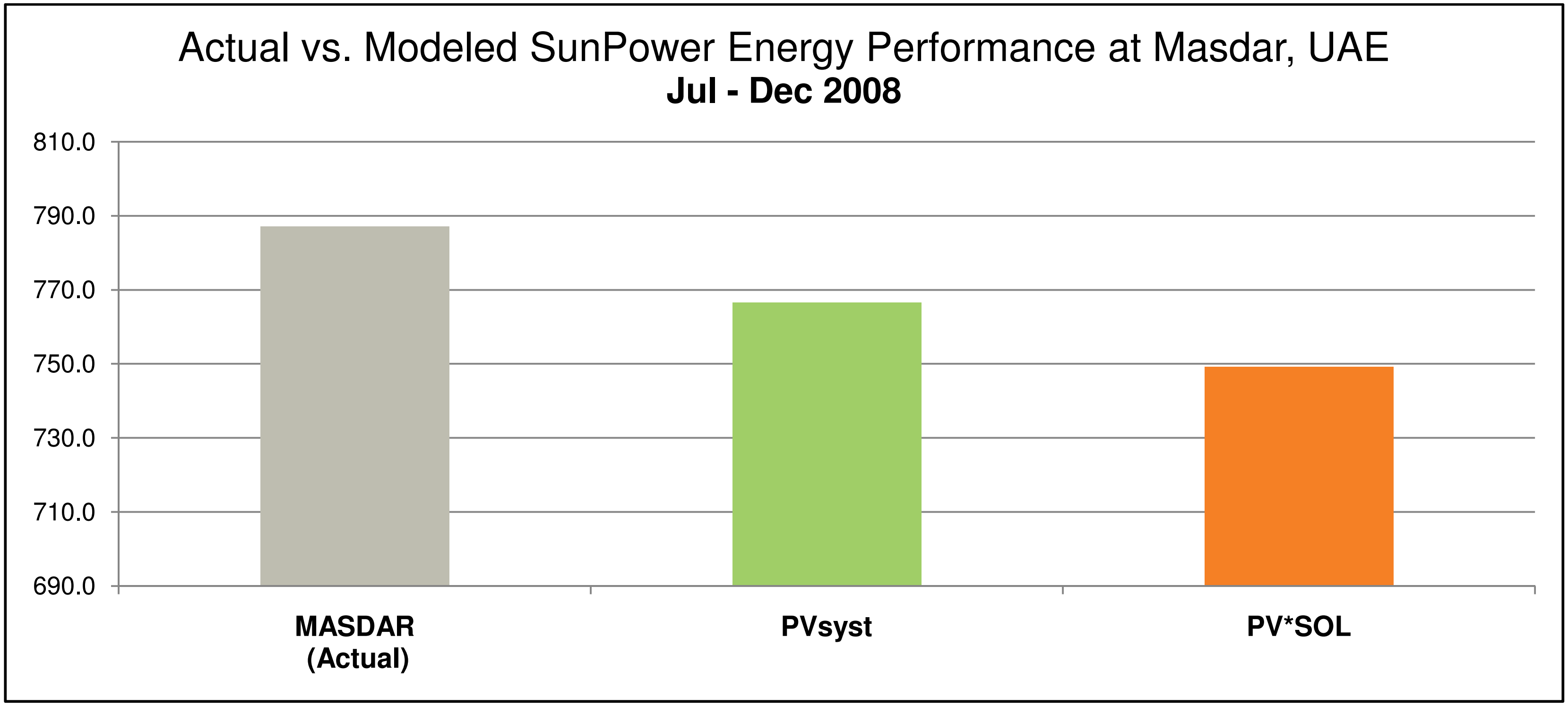
SunPower outperforming thin film and CIGs systems by a wide margin



* Note that array power for Kaneka array was measured during Staebler-Wronski stabilization

kWh Performance Modeling Inaccuracies

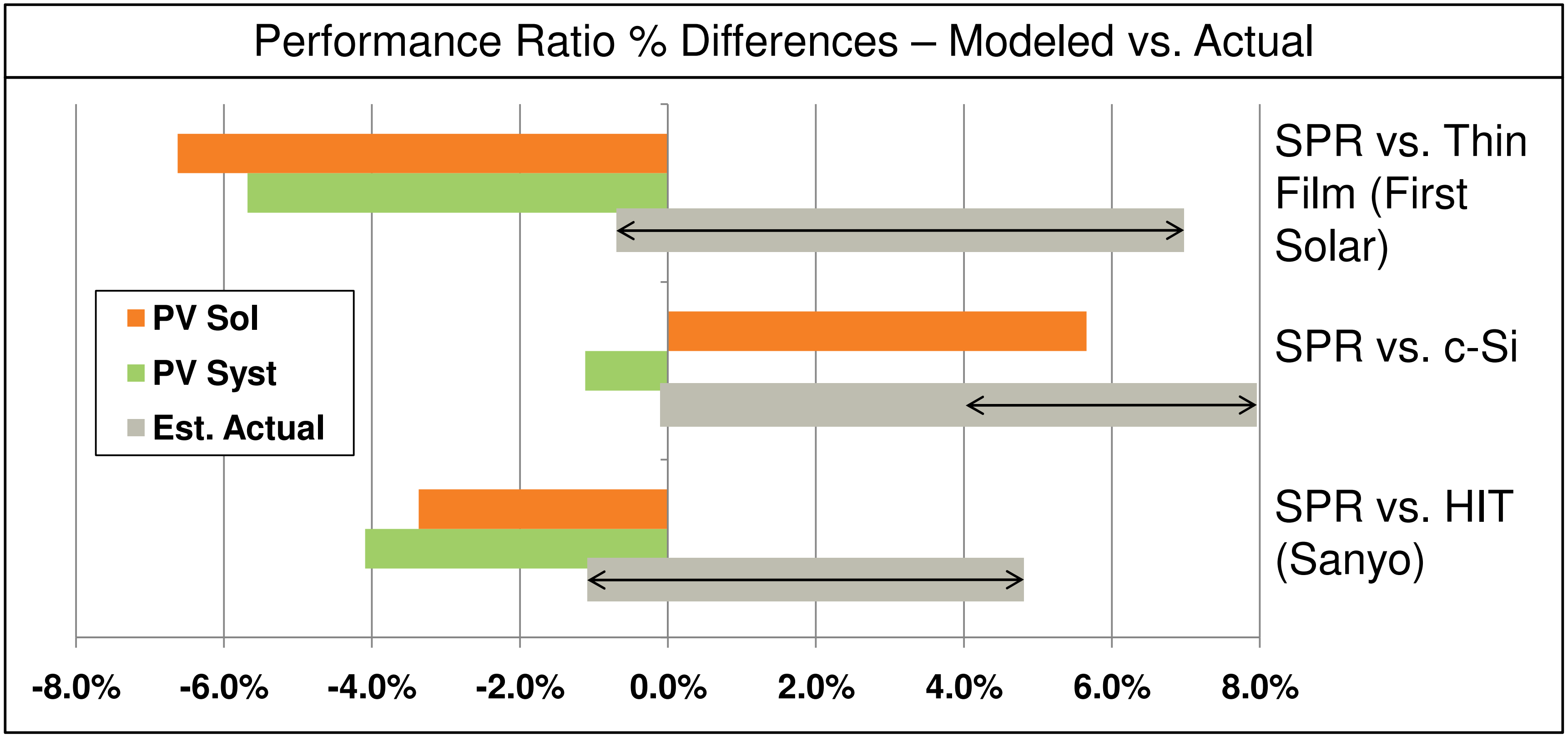
1) Models seem to *under-estimate* SunPower actual performance



Source: Data supplied by Masdar. Data pertains two SPR-300-WHT-I modules which are being tested relative to other technologies at Masdar test site.

kWh Performance Modeling Inaccuracies

2) Models seem to *under-estimate* SunPower performance relative to other technologies



Models based on performance for Madrid, Spain. Estimated actual range based on data from side by side tests, SunPower customers and SunPower's own data & models

kWh Performance Modeling Inaccuracies

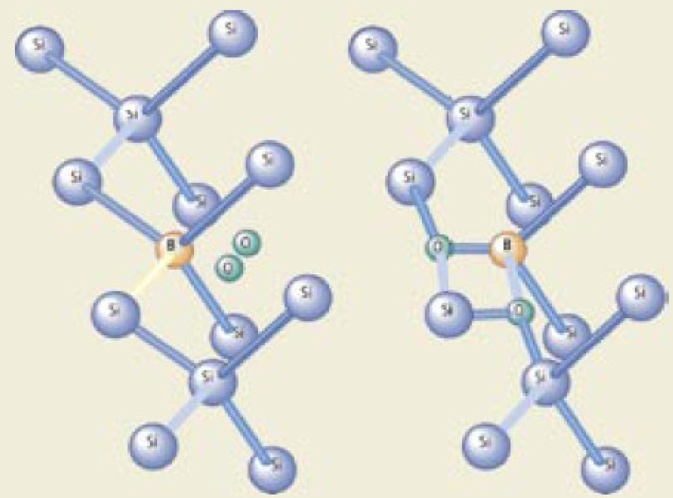
1. Models seem to *under-estimate* SunPower actual performance
2. Models seem to *under-estimate* SunPower performance relative to other technologies

Recommendation: Investors / integrators should ensure system performance projections are benchmarked to actual regional data

No Light Induced Degradation (LID) - causes

Light induced degradation is caused by an interaction between boron doped silicon (used in p-type solar cells) and oxygen. This effect has been documented by many research institutes

The boron-oxygen complex and the degradation it causes



As long as the boron atom has its electron hole, the oxygen dimer ignores it (left). A photoreaction causes the boron to lose its hole, turning itself into a negatively charged ion, which attracts oxygen – a boron-oxygen complex is formed (right) that's responsible for module degradation.

First and foremost, the element oxygen is responsible for degradation in monocrystalline modules. When growing ingots using the Czochralski process, the liquid silicon comes into contact with the gas, small amounts of which are then lodged in the semiconductor element's lattice structure. It's always two oxygen atoms that diffuse through the silicon lattice in the form of dimers, but they don't cause any damage. The degradation only occurs when oxygen builds a complex with the doped boron acceptor in the semiconductor structure.

The catalyst for the entire process is light, which starts the photoelectric effect. As soon as a boron atom loses its electron hole, energy is released. That attracts the oxygen dimer until it binds with the boron, which is present in the lattice as a single negatively charged ion following the photoreaction, while the dimer is double positive charged. The boron-oxygen complex builds its own energy level in the silicon lattice and can capture electrons and holes, which are then lost to the electricity production process. This in turn decreases efficiency and therefore the power of the module in question. The Institute for Solar Energy Research Hameln (ISFH), which has been working with this subject matter for more than 10 years, speaks of an efficiency loss of about 3 percent.

The magnitude of the degradation is linearly dependent on the boron concentration in the silicon lattice, and grows quadratically with the concentration of oxygen. Depending on silicon quality, the degradation halts at a certain point after a particular amount of time. After an exponential increase, low-ohmic materials reach their saturation after 10 hours, and high-ohm materials take one to two days. *iru*

* Excerpt from Photon International article, "A Call for Quality", March, 2008

No Light Induced Degradation (LID) - Solution

- Light induced degradation can be avoided by using phosphorus doped n-type cells.

- Rather than being science fiction as the researchers in the Photon article (see excerpt to right) suggest, SunPower is already producing n-type cells with up to 23% efficiency today!

- SunPower is one of only two module manufacturers able to make n-type solar cells and the only capable of making an n-type all-back contact cell

> Schmidt feels substituting the two-doped elements for boron is a promising solution. During ingot production, phosphorous is used rather than boron, the result is negative not positive doped wafers. In cell production, boron has to be used rather than phosphorous, as usual. That would completely eliminate the degradation effect. »In terms of technical costs, it would be identical to conventional processes, but cell manufacturers have to completely alter their cell structures and production cycle,« says Schmidt.
>
> These efforts would have benefits beyond taming degradation. Tests at ISFH show that these methods could allow for the production of high-power cells with an efficiency of 19 percent or perhaps even more. And

* Excerpt from Photon International article, “A Call for Quality”, March, 2008