



# Reliability of Grid-connected Photovoltaic Systems, the learning Curve in Yield and System Cost

23<sup>rd</sup> European Photovoltaic Solar Energy Conference and Exhibition  
Valencia, Spain  
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# Overview

- Can you name the five disciplines of the 2008 Solar Olympics?
- What is the economical progress in PV from 1991 to 2006?
- Where and how big is the technological evolution in PV?
- How can you achieve  $\varnothing$  Performance Ratio (PR) of 0.80 for your PV system?
- Why is System performance over lifetime so important for our customers and the PV industry?
- Conclusions  
The Evolution of PV systems in seven theses

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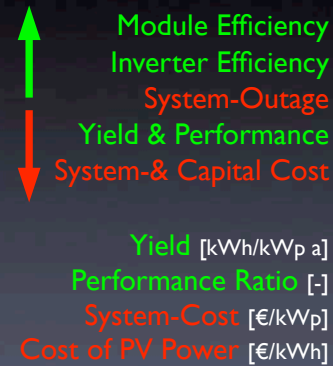
# Can you name the five disciplines of the Solar Olympics?



Modern Pentathlon!  
Moderner Fünfkampf

- Shooting
- Fencing
- Swimming
- Riding
- Running

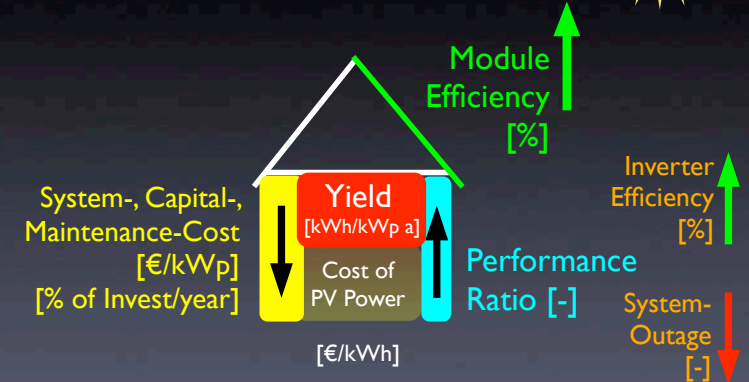
No need for Swiss Timing!



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# The Solar Olympics!



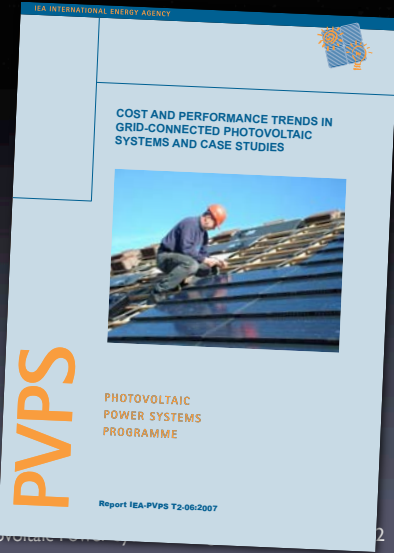
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# Focused Cost and Performance Trends 1991 - 2006

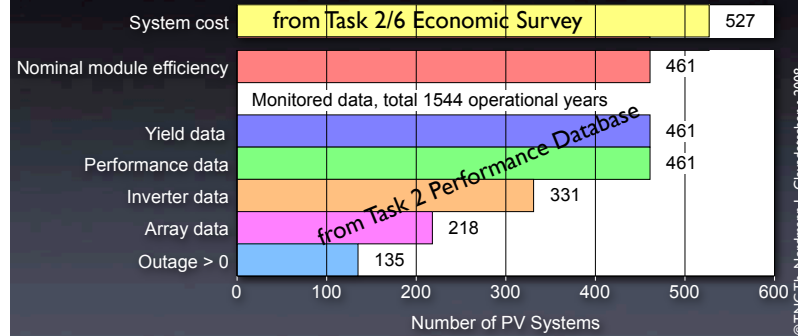
## PVPS Report T2-06:2007

Published:  
December 2007

Some free copies  
PVPS booth  
Hall 1 Stand D7/EPIA

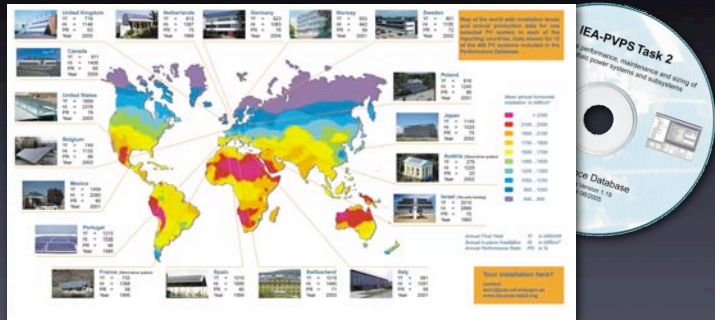


# Two Data Sources: 527 PV Systems in Task 2 Economic Survey 1'544 Operational Years in Performance DB

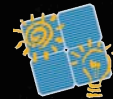


# Task 2 Performance Database

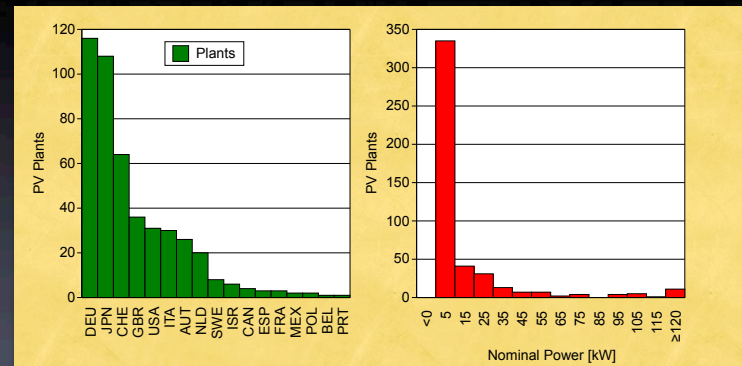
Information on 505 PV plants in 21 countries worldwide with  
13.5 MW total power and over 1'600 operational years



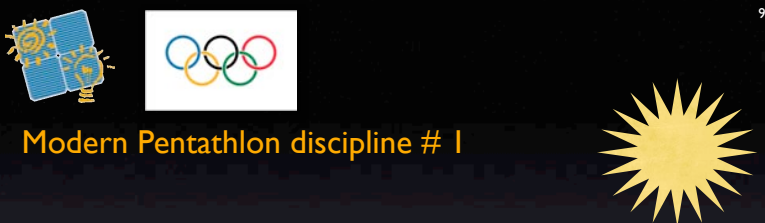
Online: [www.iea-pvps-task2.org](http://www.iea-pvps-task2.org)



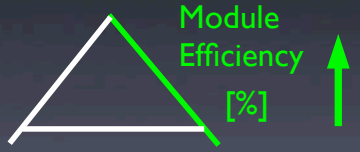
# From where & how large are the Systems? The Evolution of the Performance Ratio



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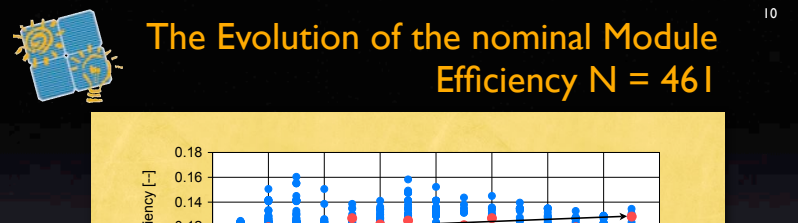
Modern Pentathlon discipline # 1



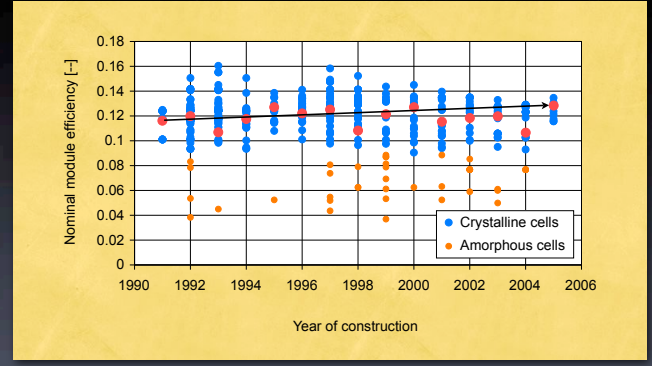
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The Evolution of the nominal Module Efficiency N = 461

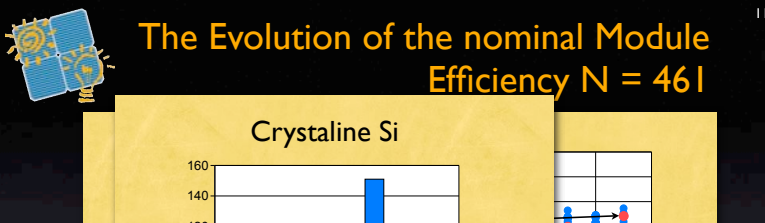


1991  $\eta_{STC} = 11.5\% \rightarrow 2005 \eta_{STC} = 13\%$ , best case 14%

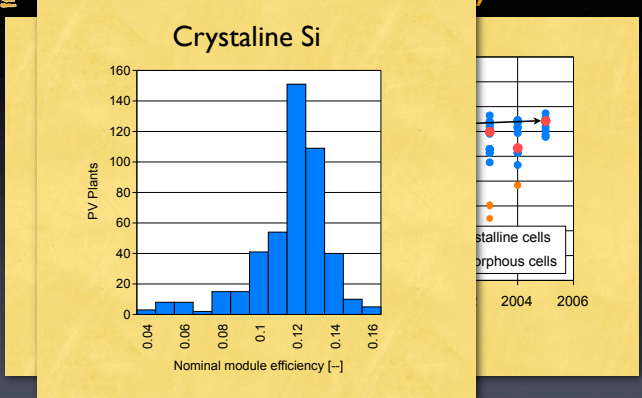
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The Evolution of the nominal Module Efficiency N = 461

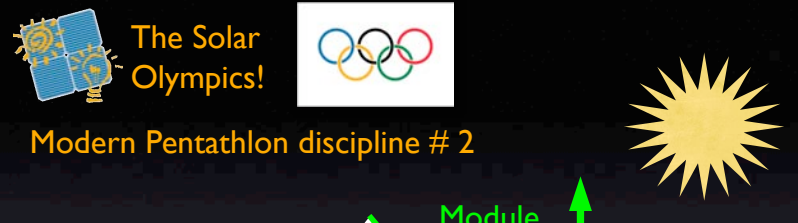


1991  $\eta_{STC} = 11.5\% \rightarrow 2005 \eta_{STC} = 13\%$ , best case 14%

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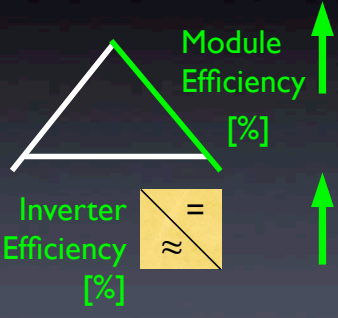
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The Solar Olympics!

Modern Pentathlon discipline # 2



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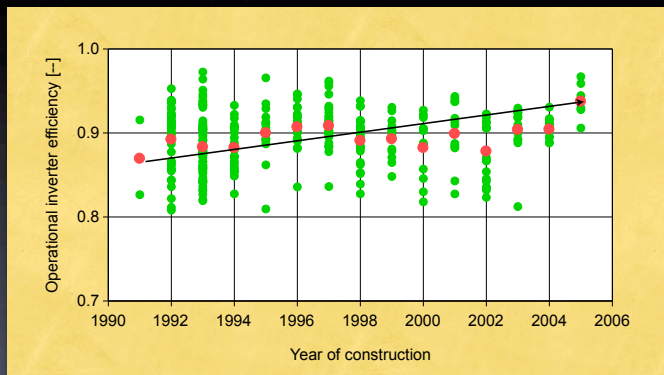
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## The Evolution of the Inverter Efficiency

N = 331

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1991  $\bar{\eta}_{INV} = 0.89 \rightarrow 2005 \bar{\eta}_{INV} = 0.94$ , Best Case = 0.94

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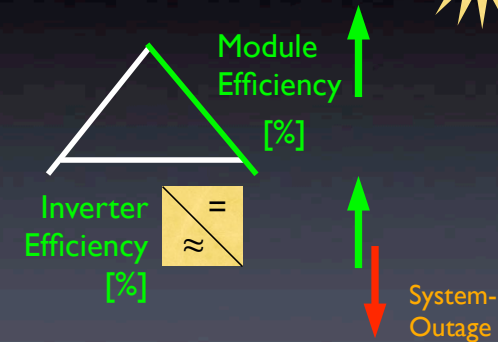
13



## The Solar Olympics!



### Modern Pentathlon discipline # 3



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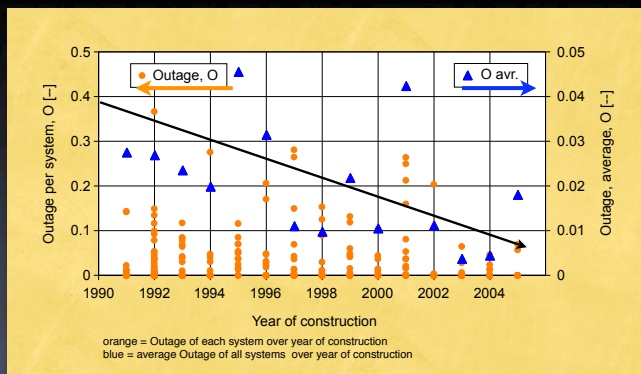
14



## The Evolution of the System-Outage

N = 135

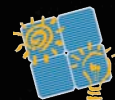
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Average 1991  $O = 0.03 \rightarrow 2005 O = 0.01$ , best case 0.00!

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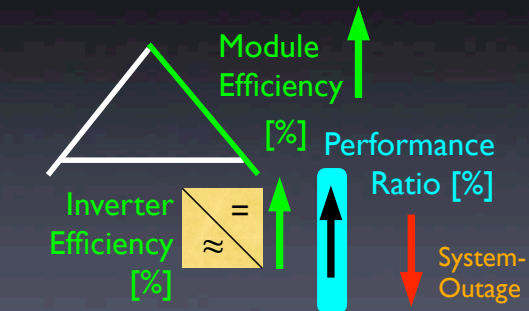
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## The Solar Olympics!



### Modern Pentathlon discipline 1+2 +3



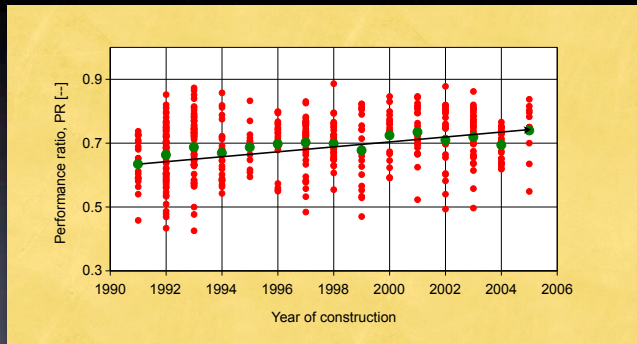
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## The Evolution of the Performance Ratio N = 461

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1991  $\bar{\text{PR}} = 0.64 \rightarrow 2005 \bar{\text{PR}} = 0.74$ , best case 0.84

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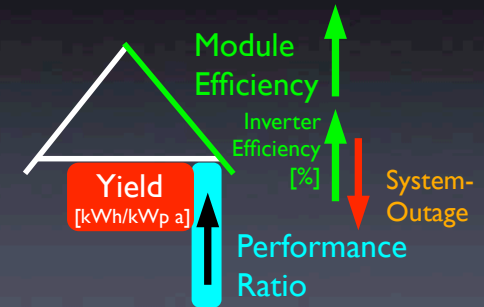


## The Solar Olympics!



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### Modern Pentathlon discipline 4



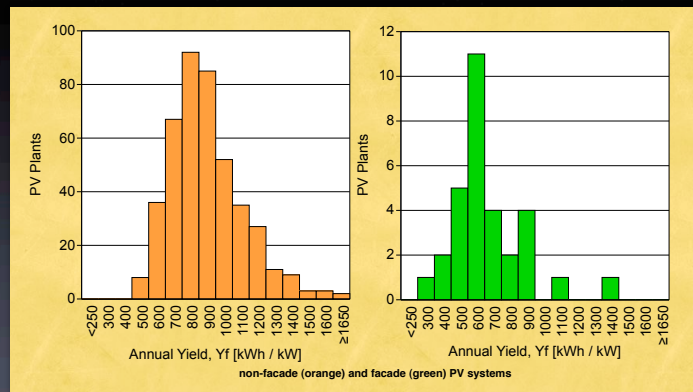
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## The Evolution of the Final Yield N = 461

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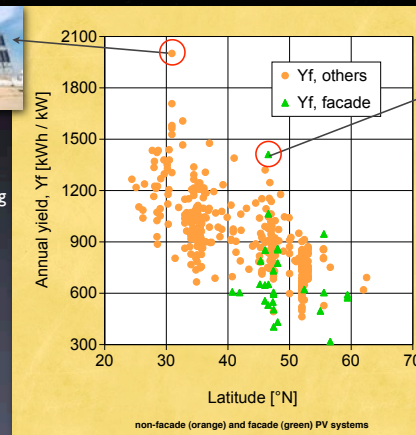


## Annual Yield to Northern of Latitude [°N]

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IEC 2ax Israel  
Grid-connected  
Two-axis tracking  
3.98 kWp  
32.3 m<sup>2</sup>  
Yf = 2'010  
kWh/kWp a



Jungfraujoch  
Switzerland  
Altitude 3,454 m  
1.15 kWp  
PR  $\bar{\text{PR}} = 85.2$   
Yf = 1'540  
kWh/kWp a  
Winter energy  
fraction 48.5%

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## How can you achieve $\varnothing$ Performance Ratio (PR) of 0.80 for your PV system?

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- Realistic, truthful module ratings
- No shading problems
- Better inverter availability and efficiencies
- Higher system availabilities, short repair times
- Early fault detection and monitoring of the systems will increase the overall performance

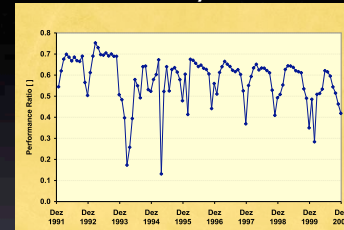
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## Dominating Performance Constraints

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### Poor reliability of inverters



### Long repair times



### Shading problems



Fotos: PVPS Task 2, TNC AG and Solar Engineering

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## Annual yield – three main groups

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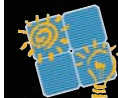
For typical PV Systems  
 461 grid-connected PV systems built 1991 - 2005  
 - from 17 countries  
 - Mainly domestic roof-top systems  
 - smaller than 10 kWp

Annual yield – three main groups:

- Israel and southern Japan  $Y_f = 1\ 400$  kWh/kWp
- Florida, USA,  $Y_f = 1\ 000$  kWh/kWp
- Central Europe  $Y_f = 900$  kWh/kWp

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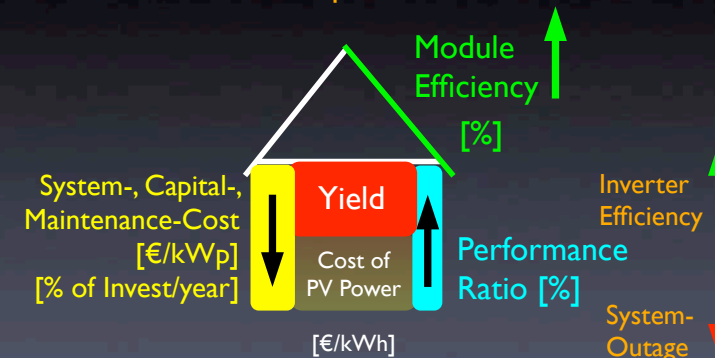
23



## The Solar Olympics!



### Modern Pentathlon discipline 5



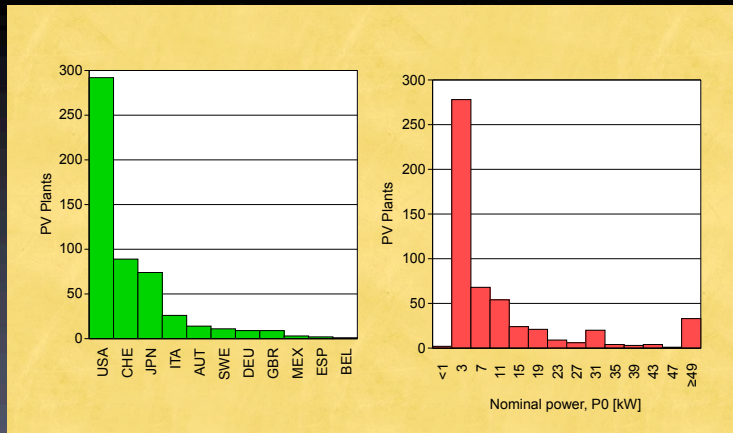
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## Task 2 Economic Survey From where & how large are the systems?

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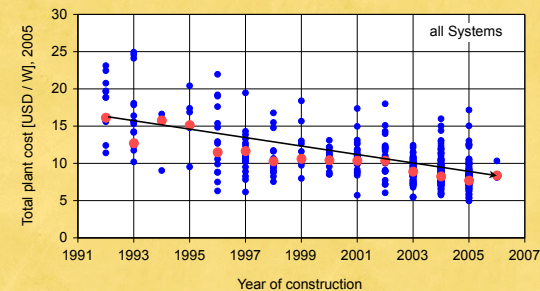
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## The Evolution of the System cost N = 527

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1992 @ 16 US\$/W → 2006 @ 8 US\$/W -50%,  
Best case 6 US\$ - 63%!

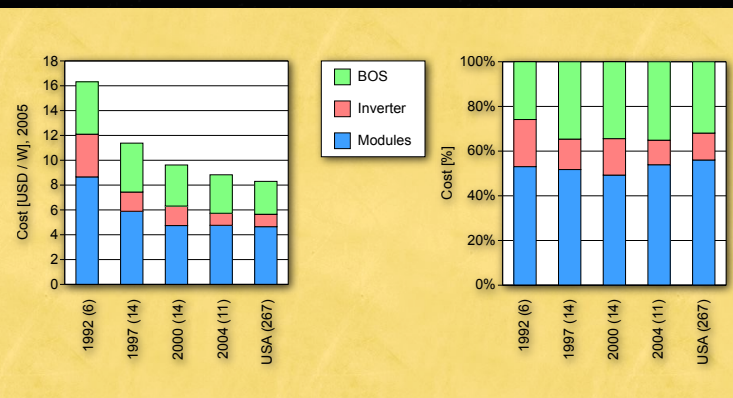
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## Cost segments: Balance of system BOS, Inverter & Modul

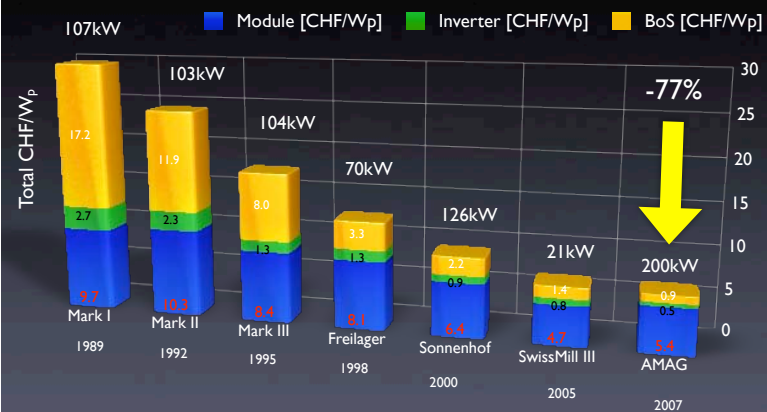
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## TNC PV systems learning-curve: 1989 - 2007



Advanced Energy Concepts

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## A typical grid connected PV system ø 1991 and ø 2005 and best case 2005

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Typical system tech.   econom.	1991	2005	2005 best case	unit
Nominal module efficiency [ $\eta_{A0}$ ]	11.6	12.9	14	%
Operational inverter efficiency [ $\eta_I$ ]	89	94	94	%
Outage ( $\phi/a$ )	0.03	0.01	0	-
Performance ratio ( $\phi$ PR/a)	0.64	0.74	0.84	-
Overall PV plant efficiency [ $\eta_{tot}$ ]	7.4	9.5	11.8	%
Improvement	100	129	158	%
Cost (in US\$ 2005 adjusted)	16	8	6	US\$/W

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## Conclusions The Evolution of PV systems in 7 theses

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- Monday  
The increase of the ø nominal module efficiency in the survey is surprisingly low 11.5% - 13% (without thin-film modules!)  
Long incubation time for new technology
- Tuesday  
The ø plant annual performance PR increases 0.64 to 0.74.
- Wednesday  
The ø operational inverter efficiency is improved from 89% to 94%.
- Thursday  
The reporting on outages and the type of failure is minimal.  
The PV industry should learn from the automobile industry.  
Zero Recall can not be achieved!

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## Conclusions The Evolution of PV systems in 7 theses

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- Friday  
Significant finding is a clear trend towards lower system cost over time from 1992 to 2006 - 50% (best case -63%)!
- Saturday  
Performance, reliability and turnkey and operational cost data of PV systems are most important for a broad PV implementation and dissemination strategy in future.
- Sunday  
Our products have a reliable and sustainable reputation.  
We have to ensure the quality of the components and the systems even in a fast growing PV environment!  
Quality and education is the key element for market developments!

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## IEA PVPS TASK 2

A Network of 17 experts from 13 countries:

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Austria  
Canada  
EU-JRC  
EPIA  
France,  
Germany  
Italy  
Japan  
Poland  
Sweden  
Switzerland  
United-  
Kingdom  
USA



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## The Task 13 Definition Workshop

- Invitation to get involved in international activities and experience
- Stakeholders: PV industry, system owners and operators, utilities
- When? **25 – 26 September 2008**
- Where? **PTJ, Berlin, Germany**

Get the Flyer for the Workshop @ the PVPS booth  
Hall 1 Stand D7/EPIA

or contact: [ch.huennekes@fz-juelich.de](mailto:ch.huennekes@fz-juelich.de)

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thank you  
for your interest

I am not a PowerPoint presentation!

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