Pico-PV-Systems: Solar Lighting and Quality Testing

Norbert Pfanner

Fraunhofer Institute for
Solar Energy Systems ISE

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www.ise.fraunhofer.de

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Overview

- Brief Introduction to White LED Light Sources
- Solar Lanterns and Pico-PV-Systems
- Quality Testing: Lighting Global's Recommended Quality Standards and Targets
- The Quality Test Method
- Quality Improvements and Issues
- Lessons Learned

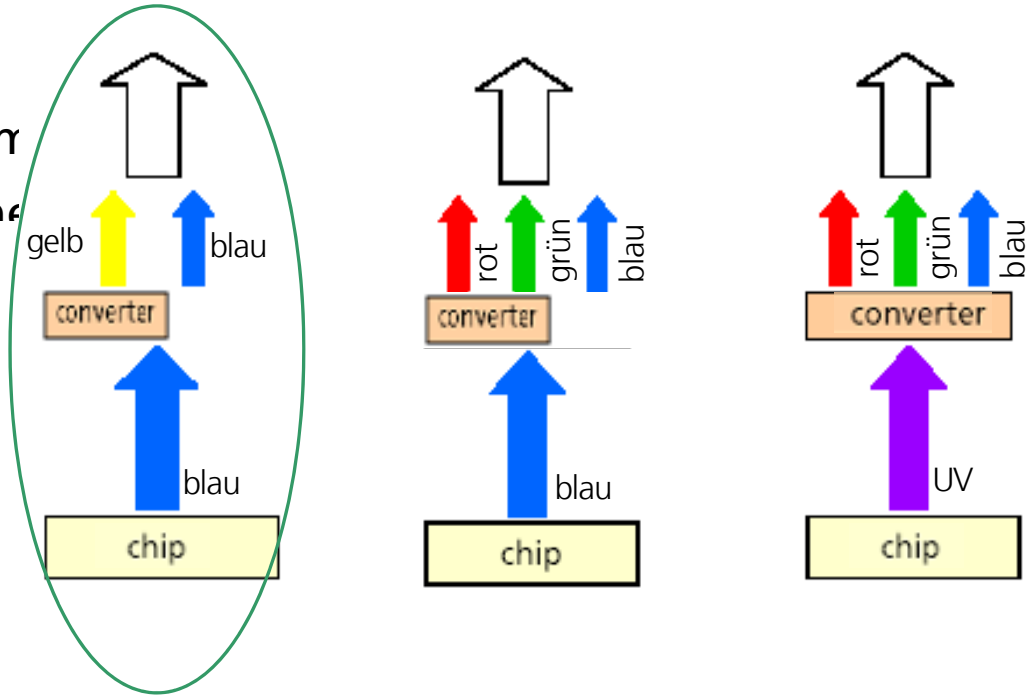
Typical Characteristics of White LEDs

- Positive
  - \+ Small to medium power consumption (ca. 0,1 W – 5 W)
  - \+ High to very high efficiency (Lumen / Watt) (typical 60 - 180 lm/W; reference incandescent lamp: 12 - 20 lm/W)
  - \+ Very high lifetime (10.000 - 50.000 hours)
  - \+ Very high switching endurance
  - \+ Fast start
  - \+ Small foot print
  - \+ High mechanical endurance
- Negative
  - – Requires Constant Current Source for operation
  - – Advanced heat management required!
  - – Currently (yet) too high priced

Working Principle of White LEDs

Luminescent - Conversion

- Light of higher frequency (blue, UV) will be transform into yellow or RGB with the help of a fluorescence substance (phosphor) and mixed to white light.



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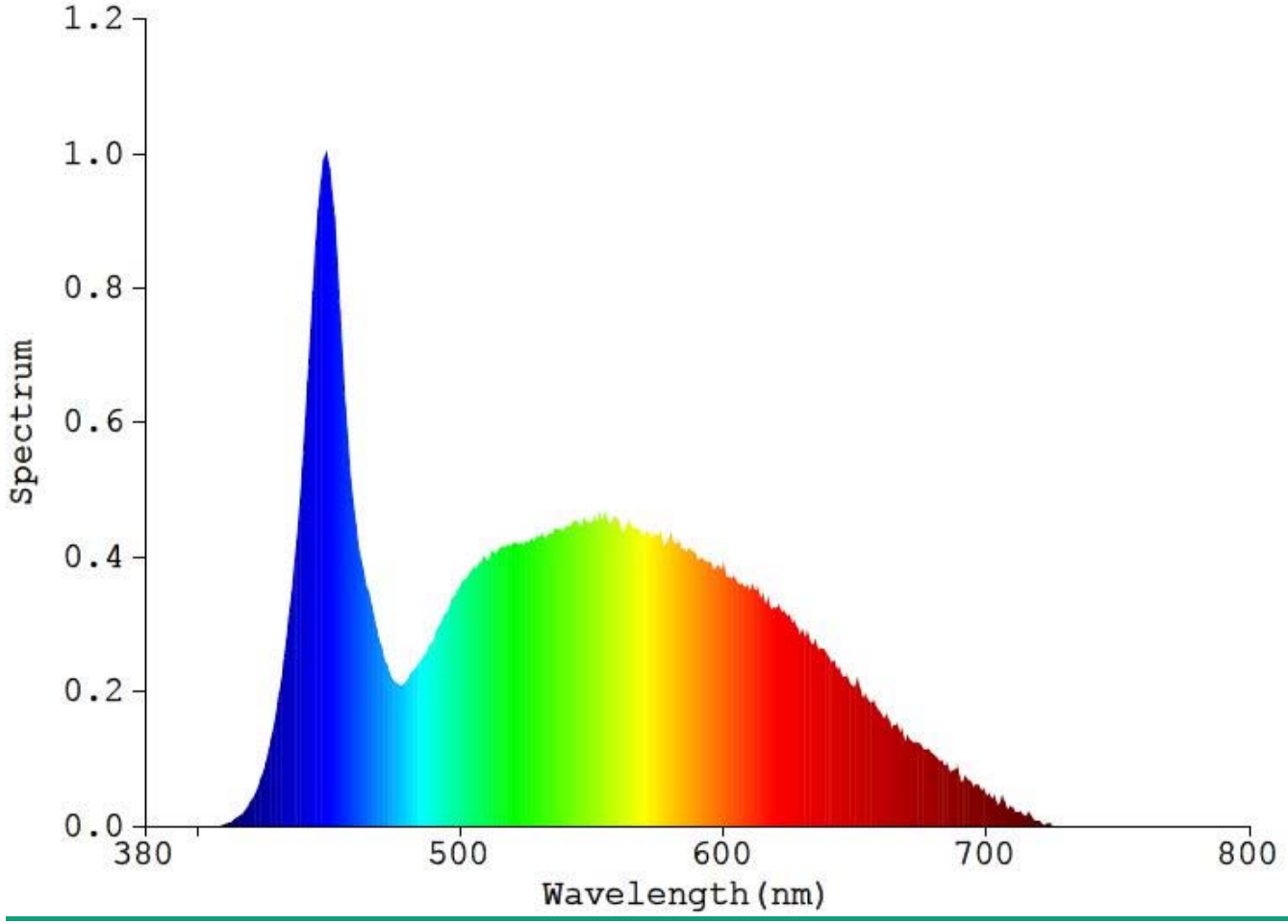
Working Principle of White LEDs

Typical Spectrum of a White LED



Source: Fraunhofer ISE ©

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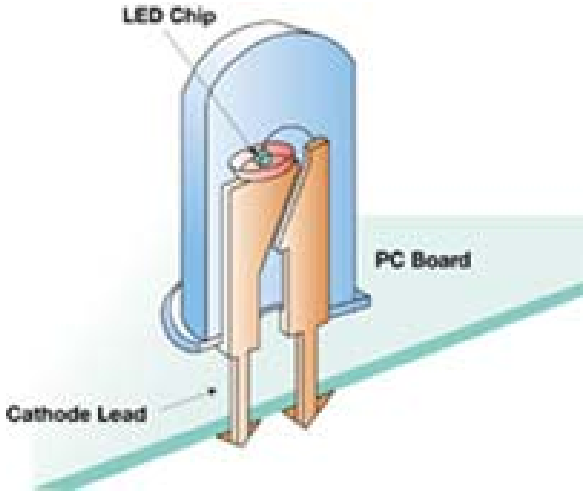
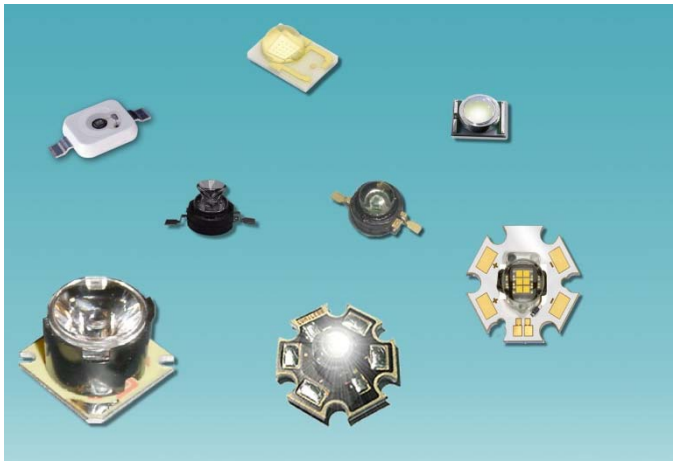
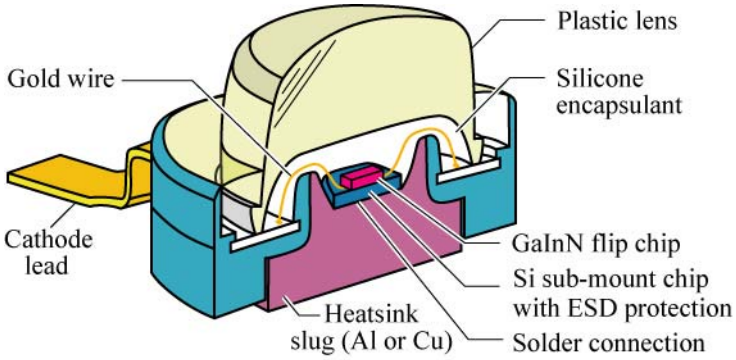
Working Principle of White LEDs

Small and medium power



High power LEDs





Source: Fraunhofer ISE, Philips Lumileds

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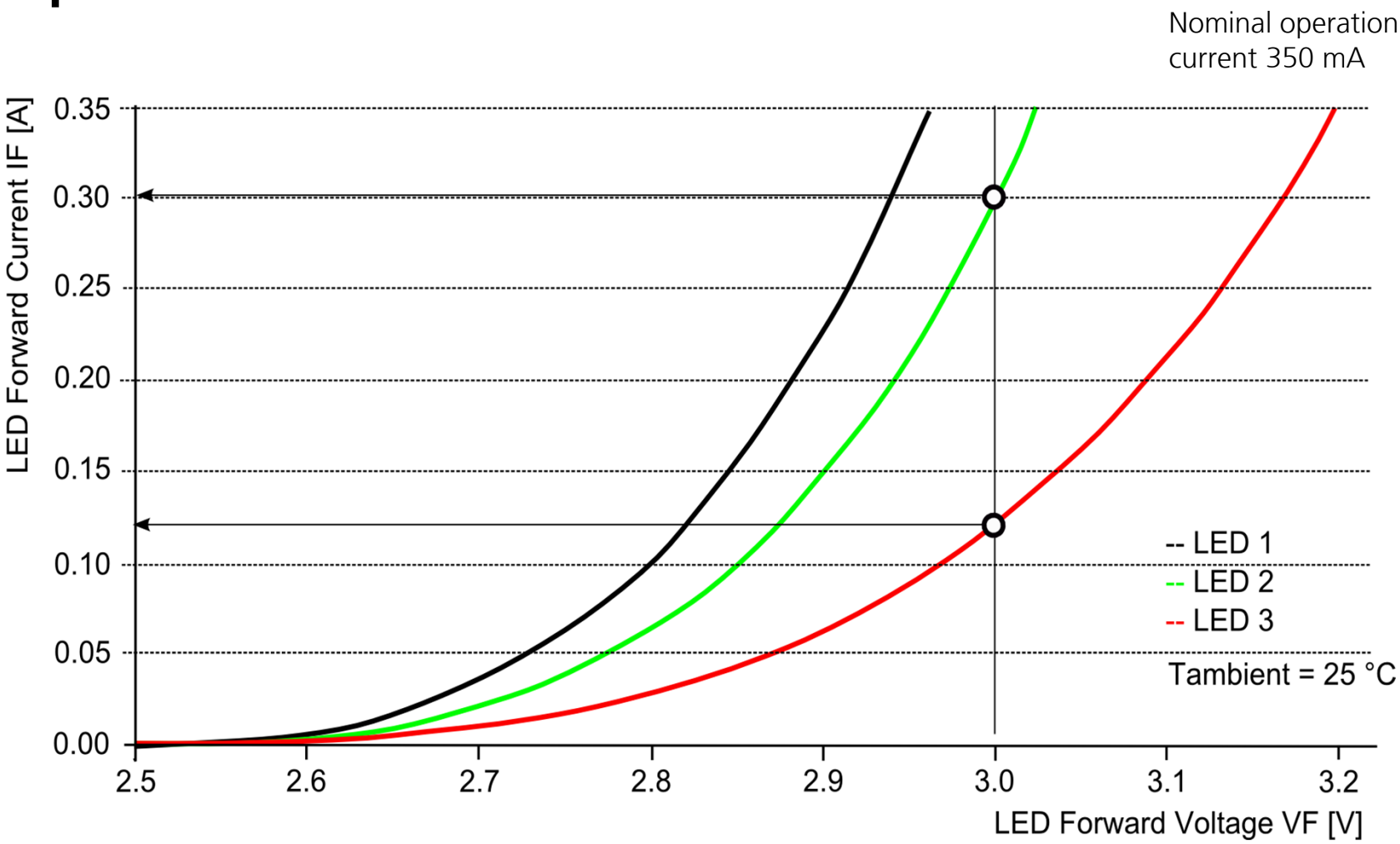
Operation of White LEDs

Important Hints

- LEDs behave like semiconductor diodes
- The LED current shows a very high dependence on LED forward voltage
- High scattering of the I-V-curves even in case of same production batch
- Forward voltage shows high dependence on temperature
  - **Consequently:** Operation with Constant Current Sources (CCS) and if at all possible connect LEDs in series!
- Even (power) LEDs produce heat!
- Maximum junction temperature of the LED chip must not being exceeded!
- High temperature load reduces lifetime of LEDs significantly!
  - **Consequently: Optimized heat-management is indispensable!**

Operation of White LEDs



Source: Fraunhofer ISE ©

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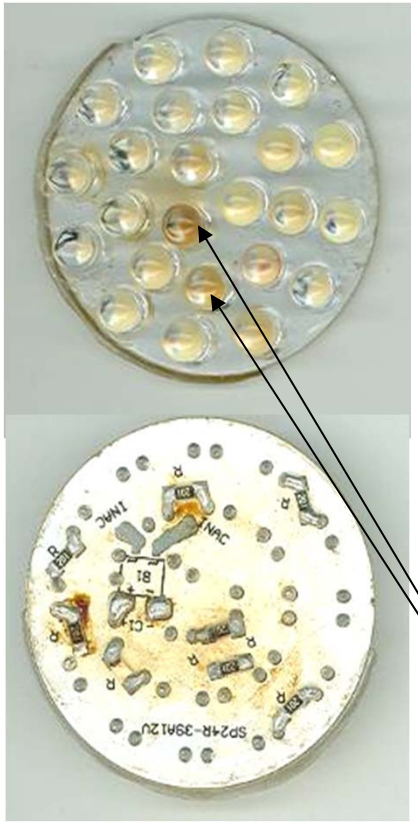
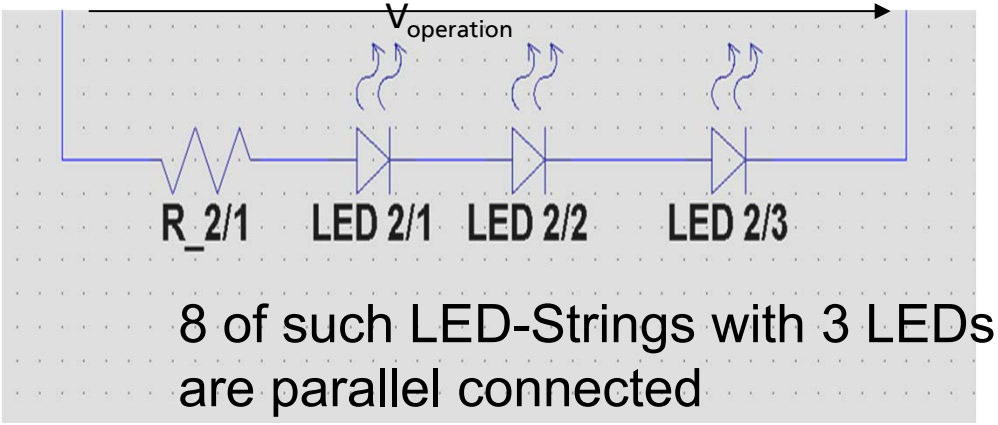
Operation of LEDs: Badly Designed LED Lamp





- Series resistor works as “current source”
- IF depends on operation voltage and temperature

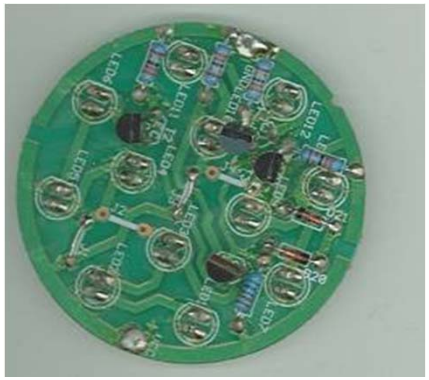
➔ Brightness related to $V_{operation}$

➔ Risk of overloading single LEDs

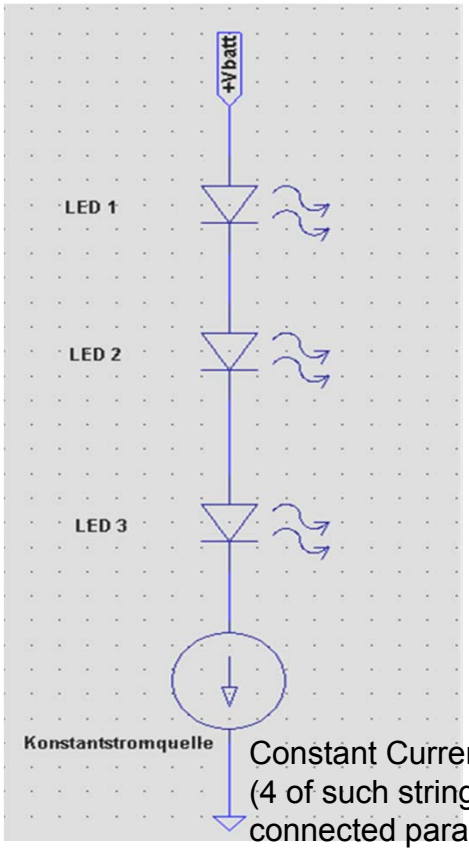
➔ Reduced lifetime!

Source: Fraunhofer ISE

Operation of LEDs: Well Designed LED Lamp



Source: Fraunhofer ISE



Constant Current Source
(4 of such strings are
connected parallel)

- One real CCS for
  3 serially connected LEDs

➔ Every LED is driven by the same constant current

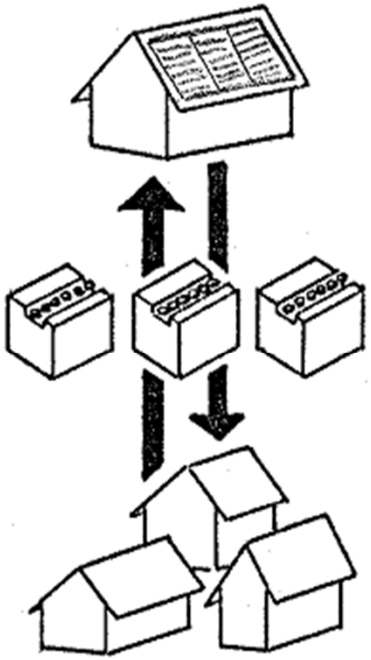
➔ Thus constant brightness

➔ No overloading =
  Enhanced lifetime

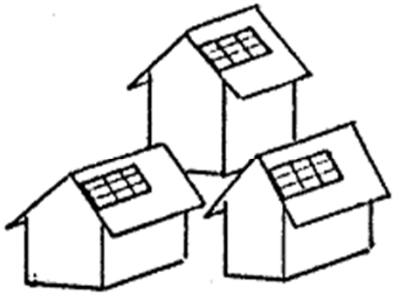
Options for Rural Electrification

Solar Lanterns
and "Pico-Systems"
3,6 VDC – 12 VDC
0,5 W – 10 W

Battery
Charging Stations
12 / 24 VDC
100 W – 1 kW

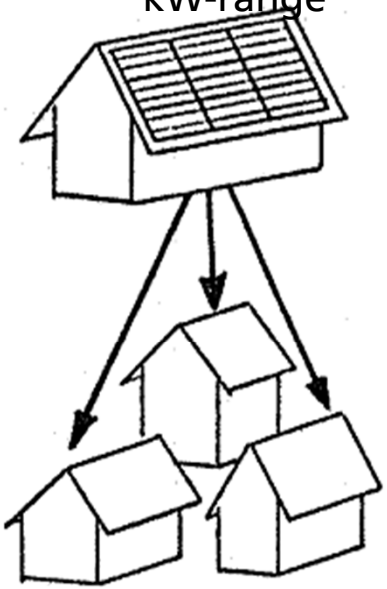


Supply
of single houses
A) DC
12V / 24V / 48 VDC
20 W – 500 W
B) AC
200 W - kW



Village
Electrification

230 VAC / 400 VAC
kW-range



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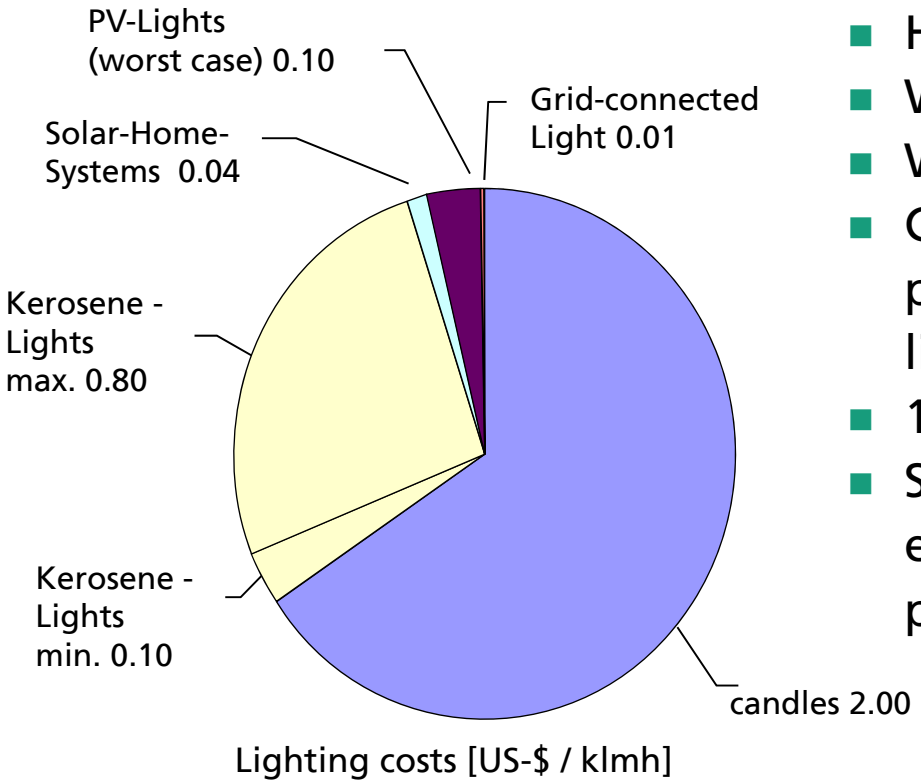
Pico-PV-Systems: Motivation and Background



Lighting costs [US-$ / klmh]

- Housekeeping costs of 40 up to 80 US-$ / a
- World-wide total costs ca. 35 Mrd. US-$ / a
- World-wide 77 bill. litres kerosene fuel / a
- Correspondent to ca. 1/3 of world-wide primary energy demand for household lighting
- 190 million tons of CO_2 per year
- Solar Home Systems for many users too expensive (Invest costs of 500 - 1.000 US-$ per system)

➔ **Pico PV Systems as an option**

Source: Fraunhofer ISE ©

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Pico-PV-Systems

Pros and Cons

Advantages

- Affordable → low operating costs compared to kerosene lamps
- Significantly increased light quality
- No soot, no fire hazard, no risk of poisoning
- Cost-effective basic electricity supply for people with very low income

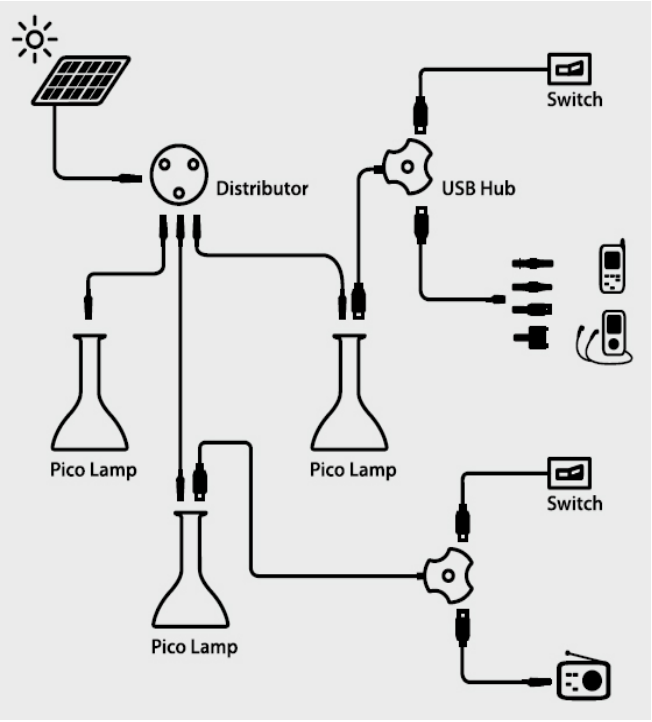
Disadvantages

- Performance very limited – it's only a first step to electrification!
- Quality of many systems not acceptable (light output, daily run time)
- A single lamp not sufficient in many cases

Bild: ISE

Pico-PV-Systems

Technical System Design



Grafik: phocos AG

- 1 - 3 Wp PV replaces one Kerosene lamp
- 0,5 W – 3 W LED as light source
- 0,5 Ah to 5 Ah battery storage (4 – 8 h run time per day)
- More and more Li-Ion batteries in use (Li-FePO4)
- Many lamps also provide a USB interface for recharging mobile phones
- Pico-PV-Systems with higher power also can supply small LCD TVs
- Some systems provide a “plug-and-play” functionality for easy upgrading

Pico-PV-Systems

Examples

www.sundaya.com
www.phocos.com
www.solarprojekt-freilassing.de
www.solux-service.com
www.dlightdesign.com
www.greenlightplanet.com
www.cosmosignite.com

Bilder: Fraunhofer ISE / Solux e. V. / Solar Projekt Freilassing e. V. / Greenlight Planet / phocos AG. Pictures not to scale!

Pico-PV-Systems – Current Focus of Fraunhofer ISE

Know-how transfer

- LED technology, „Solid-State-Lighting“
- Simulation of PV LED systems and optics
- Consulting LED lighting

Research and development

- Portable lights, street lighting, ambient lights…
- Electronics: DC/DC converters, ballasts

Quality assurance and tests

- Electrical tests and measurements: efficiency, performance, reliability
- Photometric measurements: efficacy, luminance, temperature behavior, life time
- Tests for GIZ and World Bank / IFC (Lighting Global)

Source: Gocke/GTZ, Fraunhofer ISE ©

Lighting Global's Quality Assurance

Lighting Global is …

- … a joint IFC and World Bank program
- … helping develop commercial off-grid lighting markets (Sub-Saharan Africa and Asia)
- … mobilizing the private sector to build sustainable markets to provide safe, affordable, and modern off-grid lighting
- Lighting Global developed a product quality assurance program to support market development, provide technical advisory services to quality oriented companies, and protect the interests of low-income consumers.
- The quality assurance program offers 3 services:
  - Product testing (LG Quality Test Method)
  - Technical advisory service
  - Product award competitions

www.lightingglobal.org

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Quality Testing: Lighting Global's Minimum Quality Standards and Performance Targets (Updated Vers. 3.1, Jan. 2013)

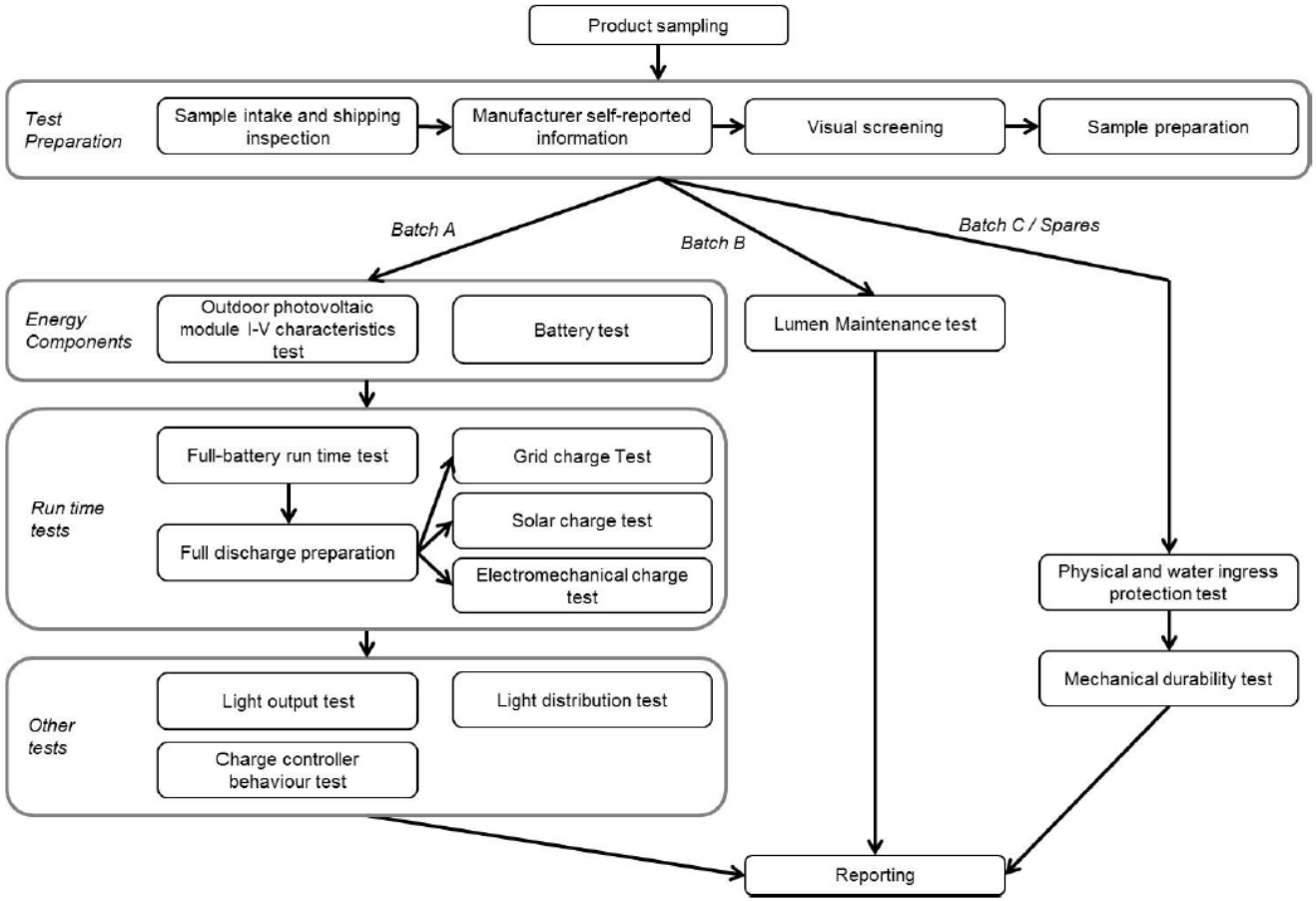
Minimum Quality Standards

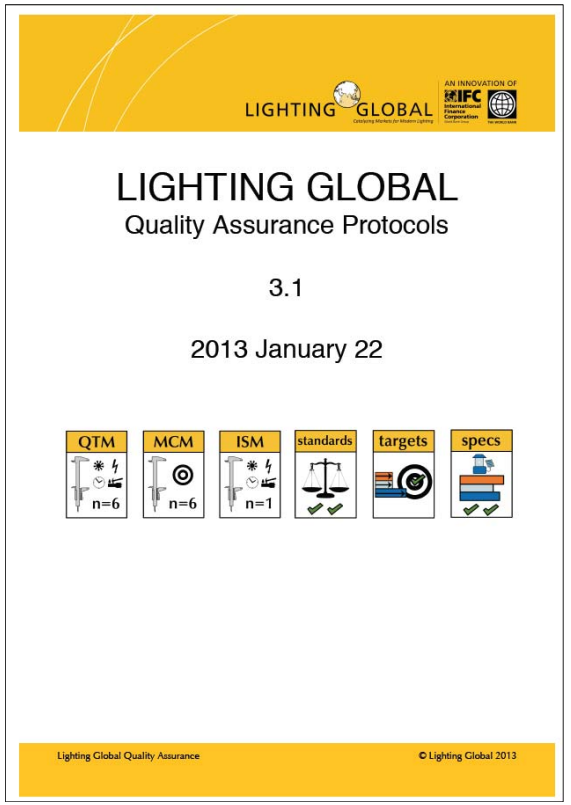
- Truth in Advertising and Warranty: Accurate consumer-facing labeling and basic 6-month warranty
- Lumen Maintenance: Average lumen output after 2,000 h of use ≥ 70% initial output or average output after 1,000 h of use ≥ 95% initial output
- Quality: Pass basic durability and quality checks
- Pass Ingress and Water Protection
- Battery Protection: Protection by an appropriate charge controller that prolongs battery life and protects the safety of the user.

Recommended Performance Targets

- Brightness: Total luminous flux ≥ 20 lumens or "useable" working area (surface with ≥ 25 lux) must be ≥ 0.1 m²
- Run Time: ≥ 8 hours full-battery run time or ≥ 4 hours solar run time at a sufficient brightness

Lighting Global's Quality Test Method (QTM)





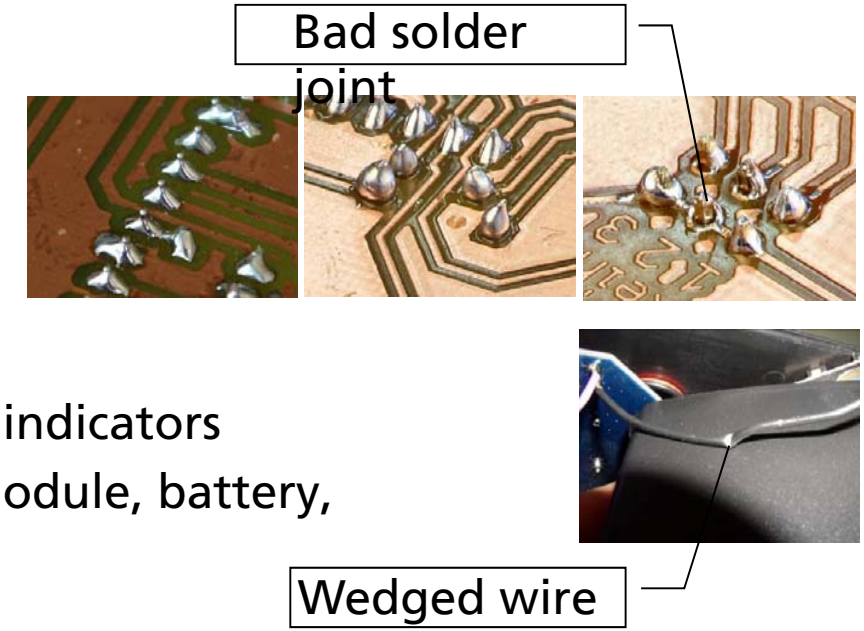
www.lightingglobal.org

Source: Lighting Global

Test Procedures

Visual Screening

- Visual screening of workmanship: cables, mounting, fixture of parts, PCB, solder joints, switches and connectors …
- Function tests: switches, connectors, indicators
- Check specifications: run time, PV module, battery, cable length ...
- Lighting services
  ➔Description of the extent of the light distribution by placing it in one of the following categories: 180° horizontal, 360° horizontal, Other
- Documentation



Source: Fraunhofer ISE

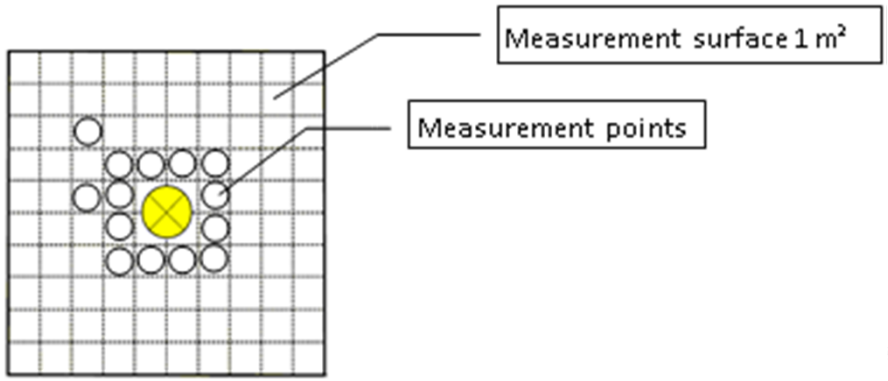
Test Procedures

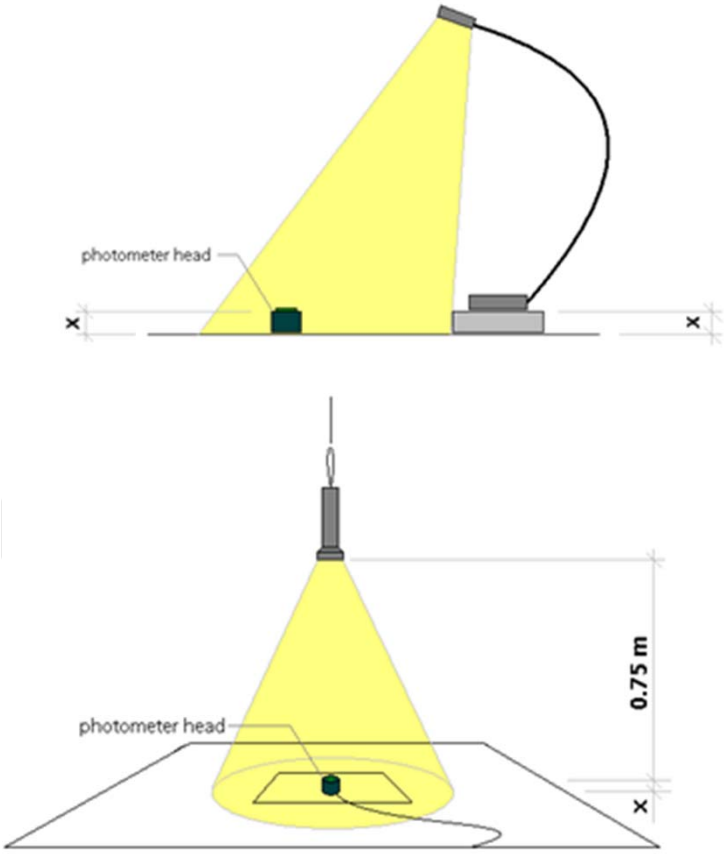
Main Test

- PV panel I-V-curve (outdoor test or lab test)
- Battery capacity
- Test of charge controllers (if appliciable)
- Assessing the autonomous time
- Detailed measurements of lighting services
- Charging behaviour (solar, grid or mechanical charging)
- Mechanical durability
- Switches and connectors
- Assessing the lumen maintenance (long term test 2000 h)

Lighting Services: Illuminance Level of Task Lights

- Measurement of illuminance levels at 100 measurement points (1 m²)
- Graphical presentation of the illuminance distribution
- Calculating the total surface average illuminance





Source: Fraunhofer ISE

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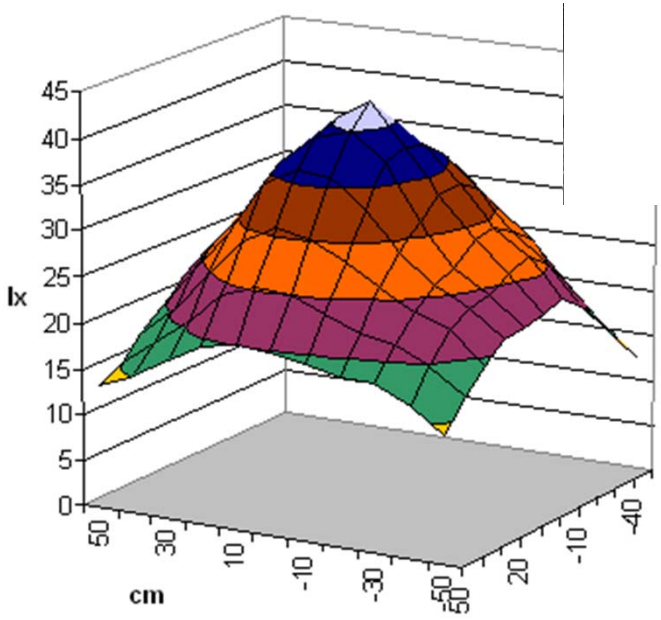
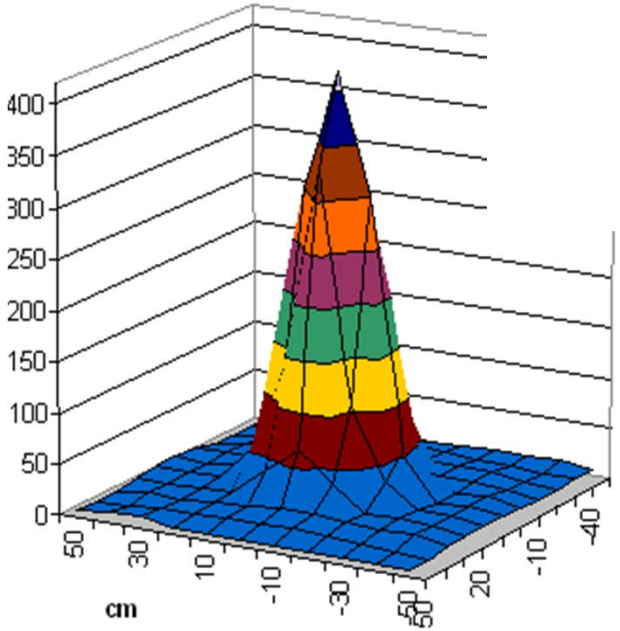
Lighting Services: Examples

Lamp 1, Ambient Light



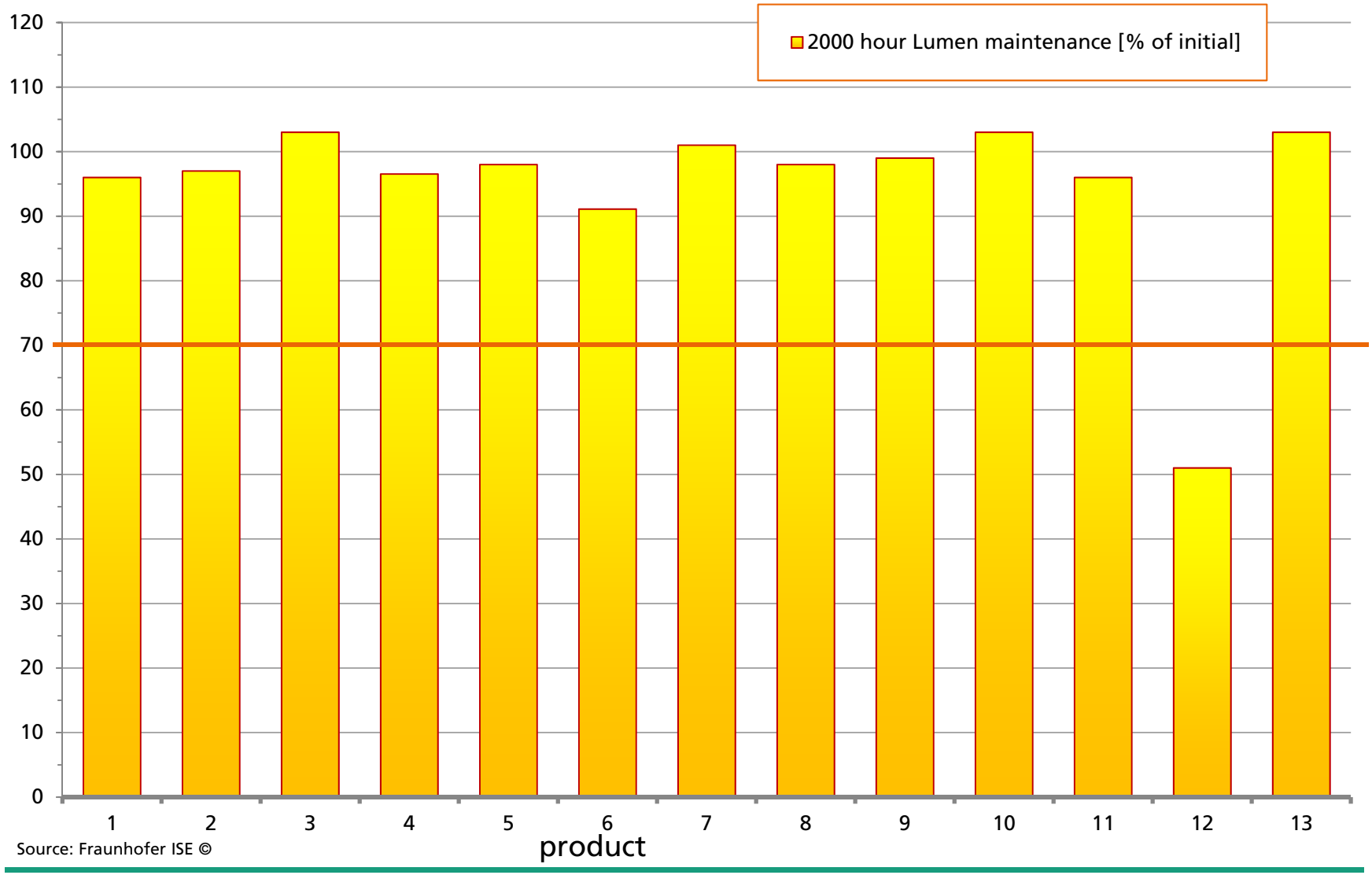
Lamp 2, Spot Light



Measurement as a Desk Light

Source: Fraunhofer ISE ©

Improvement of Performance: Lumen Maintenance



Source: Fraunhofer ISE ©

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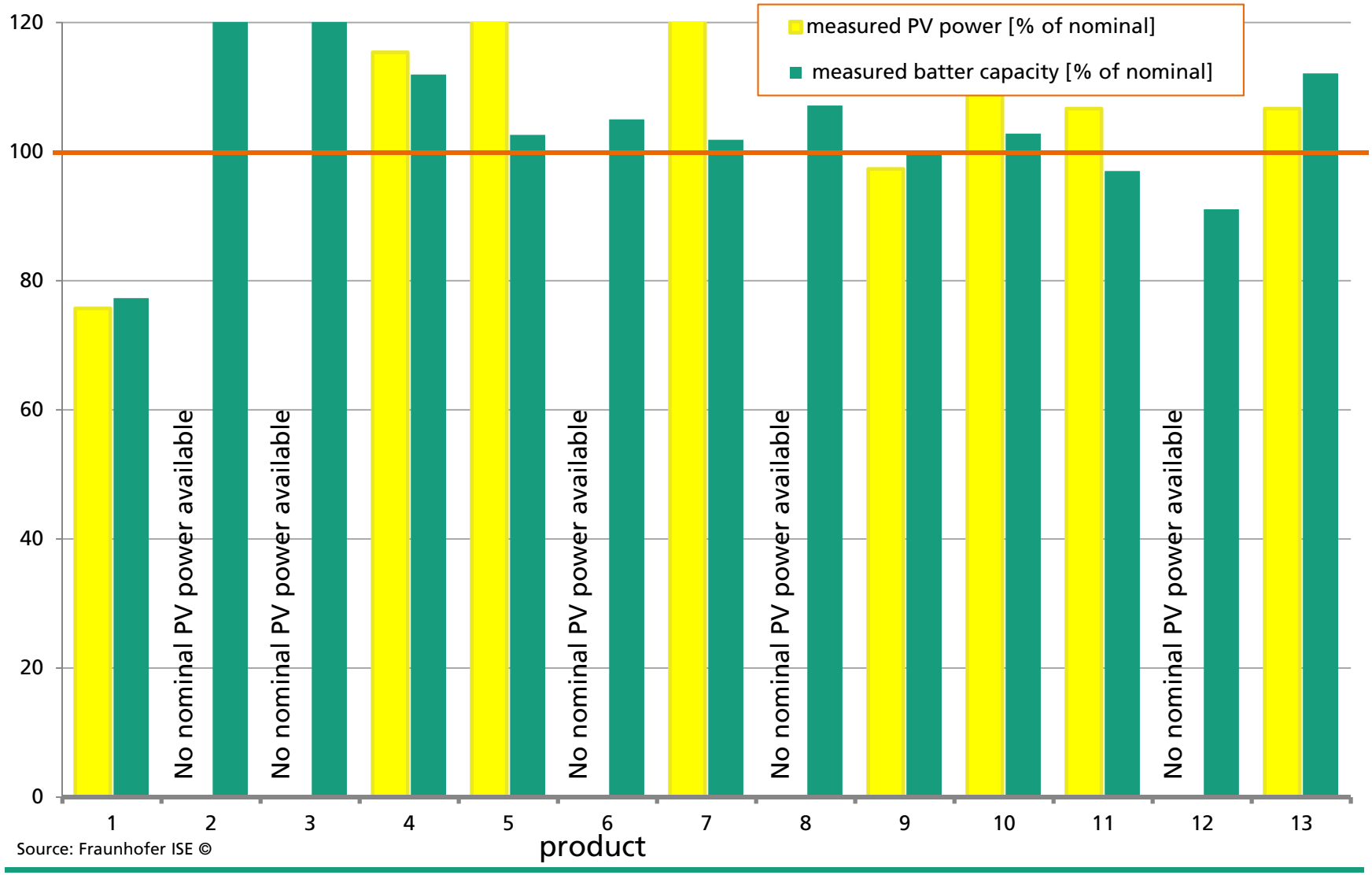
“Truth in Advertising”: PV power and battery capacity



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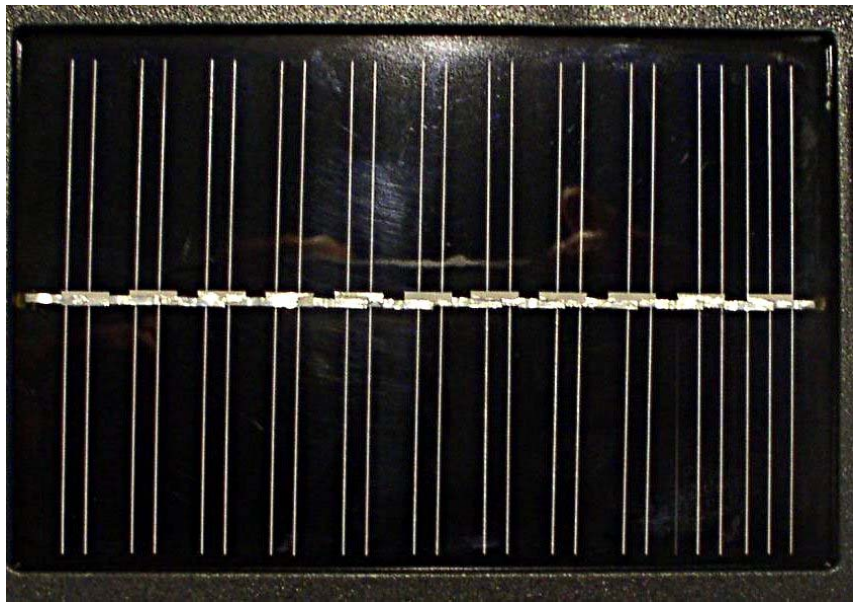
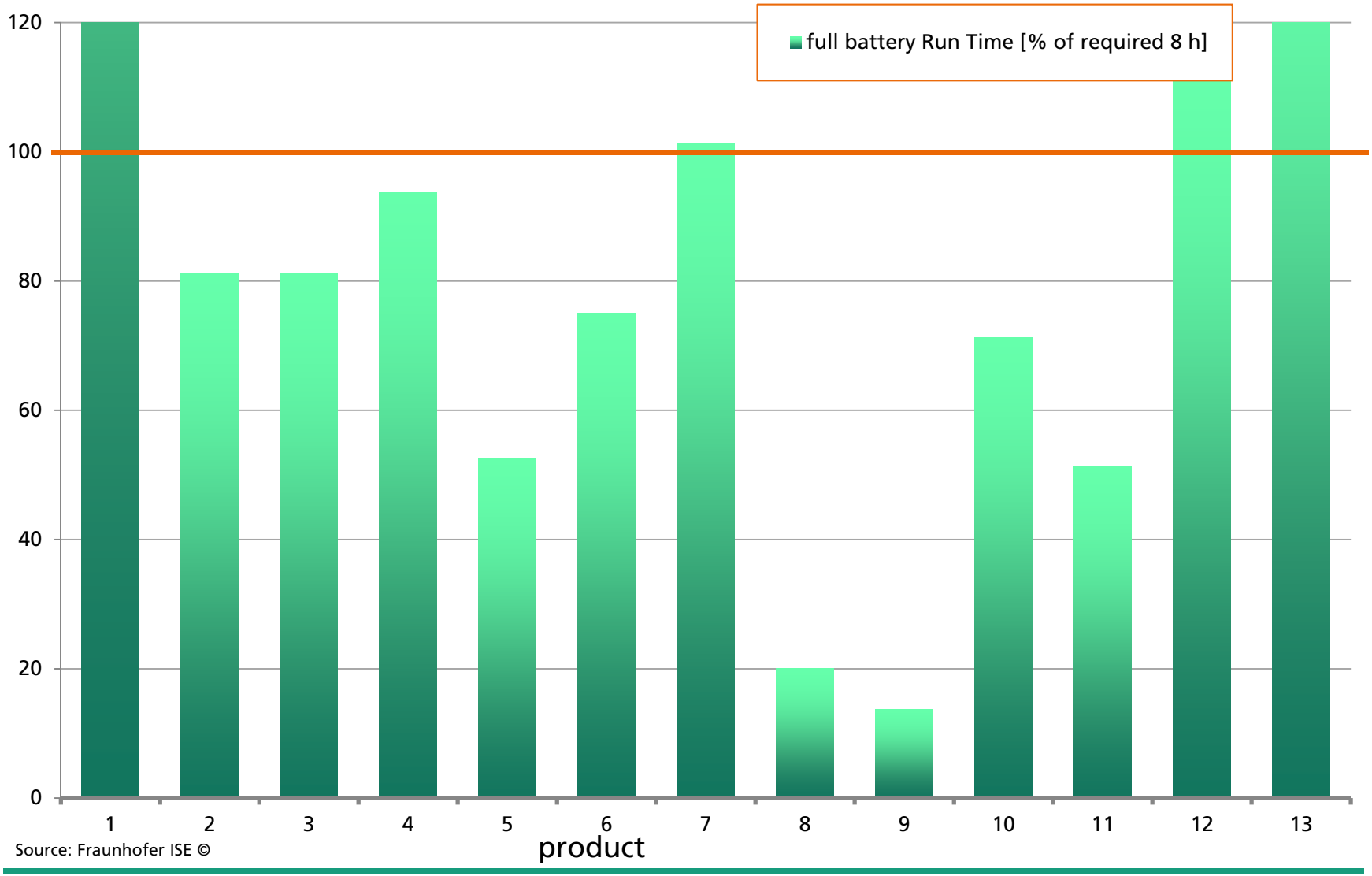
Quality Assurance PV Modules



- Different sizes of solar cells
- Broken cells

Source: Fraunhofer ISE ©

Run Time Issues: full battery Run Time (autonomous time)



Source: Fraunhofer ISE ©

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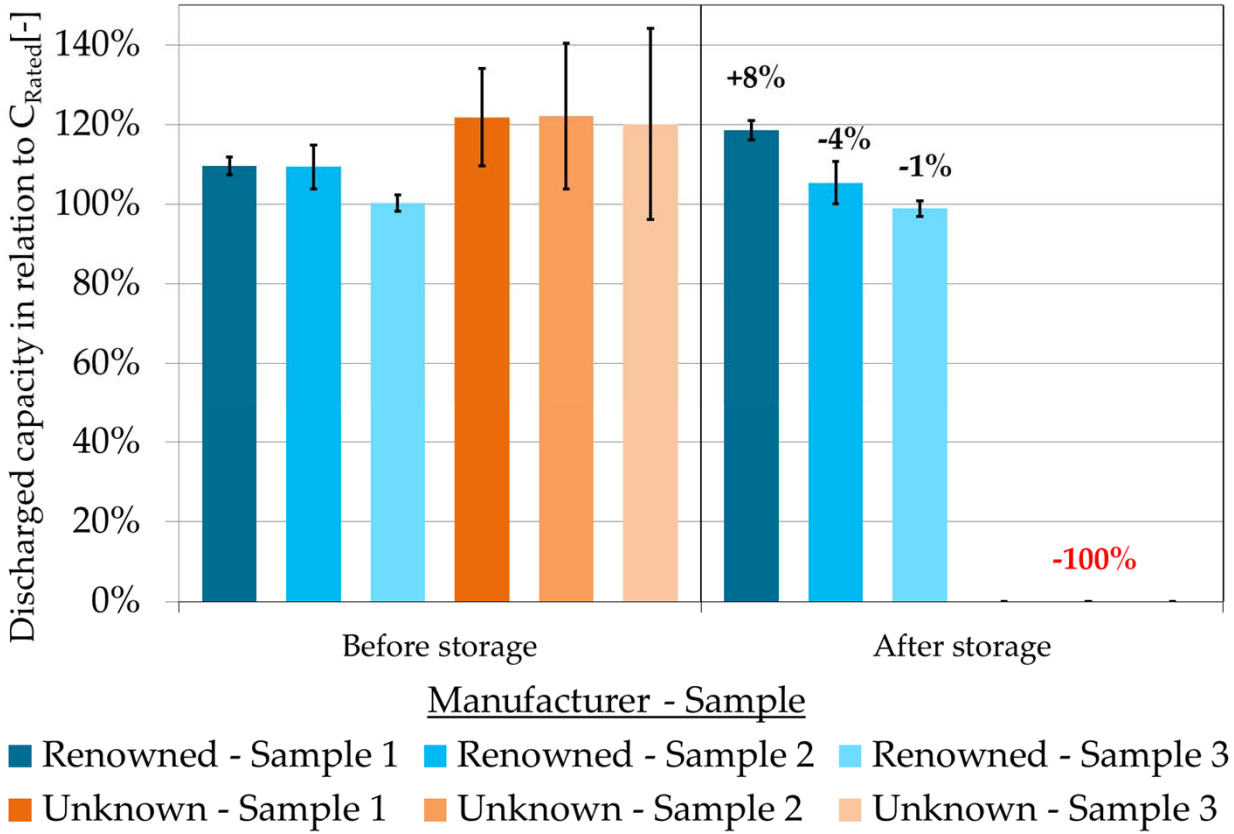
Battery Qual. Issues – Lead-acid batteries: storage test

- Batteries were discharged and stored inside a turned off solar lantern for a period of 3 months at 30 °C

- Unknown manufacturer: None of the samples could be recharged after the three months: **100 % capacity loss**

- Renowned manufacturer: Only very small capacity losses



Source: Fraunhofer ISE ©

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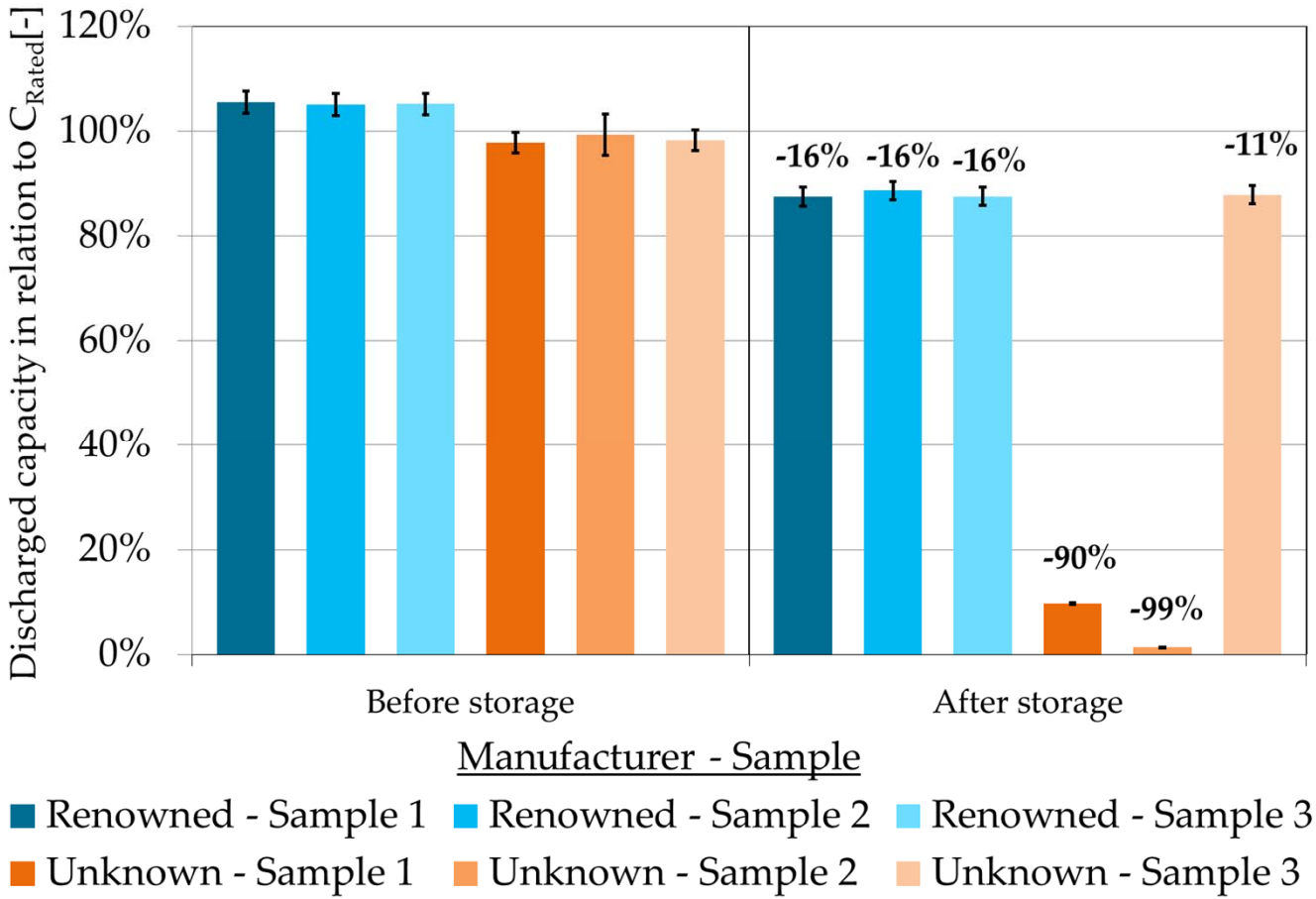
Battery Qual. Issues – Lithium-ion batteries: storage test

- Batteries were stored at 60 °C during 30 days with a SOC of 50%

- Unknown manufacturer: Large scattering and high capacity losses

- Renowned manufacturer: Capacity losses < 20%



Source: Fraunhofer ISE ©

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Battery Test Results Summary

		Storage tests		Cycle tests	
		Tested	Passed	Tested	Passed
Lead-acid batteries		3	**2**	2	**1**
NiMH batteries		5	**2**	6	**5**
Lithium-ion batteries	**$LiCoO_2$**	3	**2**	2	**2**
	$LiFePO_4$	5	**5**	2	**2**
Total		**16**	**11**	**10**	**8**

Source: Fraunhofer ISE ©

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Lessons Learned

- Since 2007 we tested more than 40 products with a total of more than 280 samples at Fraunhofer ISE's Lighting Lab
- In total we recognized a **clear increase of the overall quality of the Pico-PV-systems and lamps**
- The current assessments showed significant **improvements** regarding **lumen maintenance, PV panel output and overall quality**
- We also observed an **increased light output** of many of the products but partly on the risk of **strong glare**
- **Battery quality remains as a key weakness!**
- Meanwhile more than 40 products have met the Lighting Global Minimum Quality Standards (see http://www.lightingglobal.org/resources/specs.)

Thank you for your attention!

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