
FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE



Photovoltaics Report

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CONTENT

- Introduction
- Executive Summary
 - PV Market
 - Solar Cells / Modules / System Efficiency
 - Energy Payback Time (EPBT)
 - Inverters
 - Price Development
- Acknowledgements

Introduction

Preliminary Remarks

- Photovoltaics is a fast growing market: Worldwide in 2011 about half of the previously cumulated PV module capacity entered the market.
- The intention of this presentation is to provide up-to-date information. However, facts and figures change rapidly and the given information may soon be outdated again.
- This work has been carried out under the responsibility of Dr. Roland Schindler (Fraunhofer ISE) and Werner Warmuth (PSE AG).
- The slides have been made as accurate as possible and we would be grateful to receive any comments or suggestions for improvement. Please send your feedback to warmuth@pse.de

Executive Summary

PV Market

- China and Taiwan entered the mass production market in 2004 and ramped up a PV industry with strong growth rates. End of 2011 their market share was 56 %, which is 13 GWp out of the 23 GWp 2011 worldwide production.
- Europe contributed 70 % of the total cumulated installations in 2011. In contrast, installations in China and Taiwan accounted for less than 10 % of the total cumulated installations.
- Bulk Si-wafer based PV technology accounted for about 86 % of the total shipments in 2011. Out of this, the share of monocrystalline technology increased over the past seven years to 40 %.
- Within thin film technology in 2011, CdTe leads with an annual production of about 2 GWp and a market share in total PV production of about 8 %. In 2011, the market share of all thin film technologies was 14 %.

Executive Summary

PV Market: Focus Germany

- In 2011 Germany accounted for about 37 % (or 24.8 GWp) of the total cumulated worldwide installed PV capacity (which totaled about 64 GWp at the end of 2011). By 2011 about one million PV systems are installed in Germany. The trend is towards bigger system size due to the support program.
- PV supplied more than 3 % of Germany's electricity demand in 2011. Renewable sources delivered about 20 % of the electricity in 2011.
- In 2011 about 10 Mio. t CO₂ emissions have been avoided due to 19 TWh electrical energy generated by PV in Germany.
- PV system performance has strongly improved. The typical Performance Ratio has increased from 70 % to about 85 % over the last 15 years.

Executive Summary

Solar Cells / Modules Efficiency

- The record lab cell efficiency is at about 25 % for monocrystalline silicon and 17 % for CdTe solar cells.
- In the last 10 years, the efficiency of average commercial wafer-based silicon modules increased from about 12 % to 15 %. At the same time, CdTe module efficiency increased from 7 % to 11 %.
- In the laboratory, best performing modules are based on monocrystalline silicon with about 23 % efficiency. Record efficiencies demonstrate the potential for further efficiency increases at the production level.
- In the laboratory, high concentration multi-junction solar cells achieve an efficiency of up to 43.5 % today. Initial projects with this concentrator technology result in about 31 % module efficiency.

Executive Summary

Energy Payback Time

- Material usage for silicon cells has been reduced significantly during the last 5 years from around 16 g/Wp to 6 g/Wp due to increased efficiencies and thinner wafers.
- The Energy Payback Time for Si PV modules is about one year for locations in Southern Europe; thus the net clean electricity production of a solar module is 95 %.
- The Energy Payback Time of PV systems is dependent on the geographical location: PV systems in Northern Europe need around 2.5 years to balance the inherent energy, while PV systems in the South equal their energy input after 1.5 years and less.
- The Energy Payback Time for CPV-Systems in Southern Europe is less than 1 year.

Executive Summary

Inverters

- Inverter efficiency for state-of-the art brand products stands at 98 % and above.
- The market share of string inverters is estimated to be 90 %. Central inverters, which typically have a power greater than 100 kWp, account for about 9 % of the total inverter market. A small proportion of the market (below 1 %) belongs to micro-inverters (for the module level) or DC/DC converters also called “power optimizers”.
- The specific net retail price in Germany is around 25 €/ct/kWp. Central inverters tend to be cheaper than string inverters.

Executive Summary

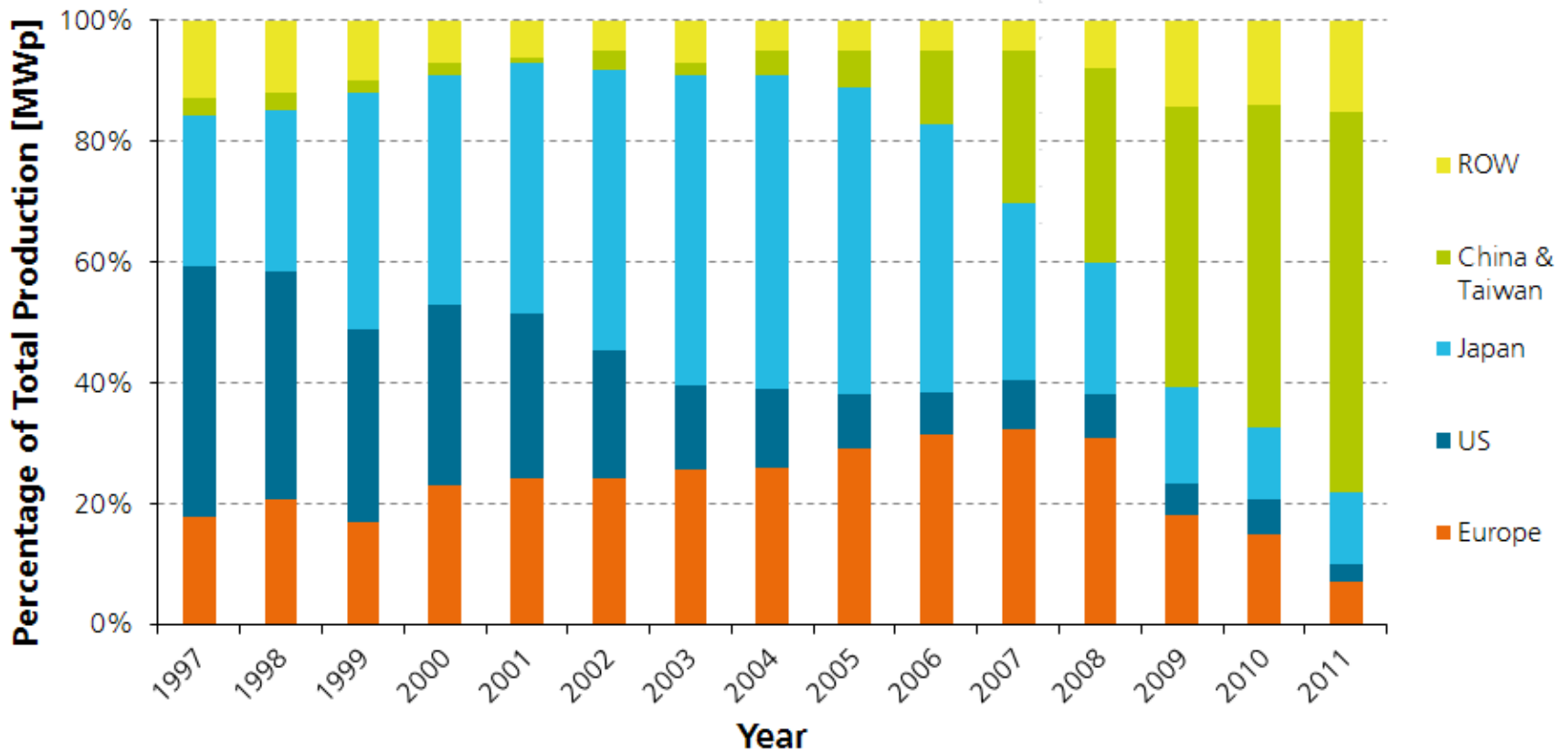
Price Development

- The long-term effect of different subsidy schemes in Germany has decreased PV system prices from around 14,000 €/kWp in 1990 to 2,100 €/kWp by end of 2011. This is a net-price regression of 85 % over a period of 21 years and is equivalent to a compound average price reduction rate of 8.6 %.
- The Experience Curve – also called Learning Curve - shows that in the last 30 years the module price decreased by about 20 % with each doubling of the cumulated module production. Cost reductions result from economies of scale and progress in research.

1. PV Market

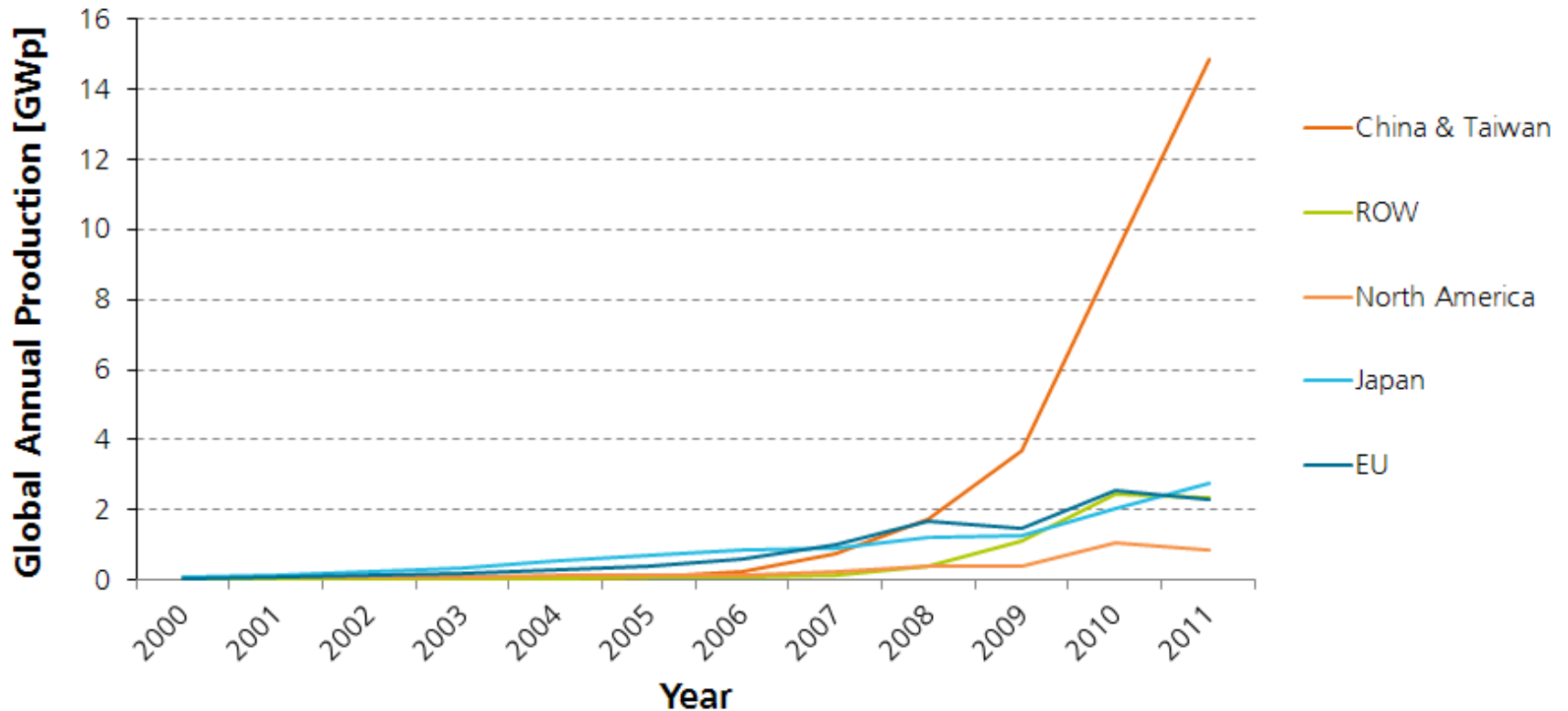
- By region
- By technology

PV Cells/Modules Production by Region 1997-2011 (Percentage of Total MWp Produced)



Data: Navigant Consulting Graph: PSE AG 2012

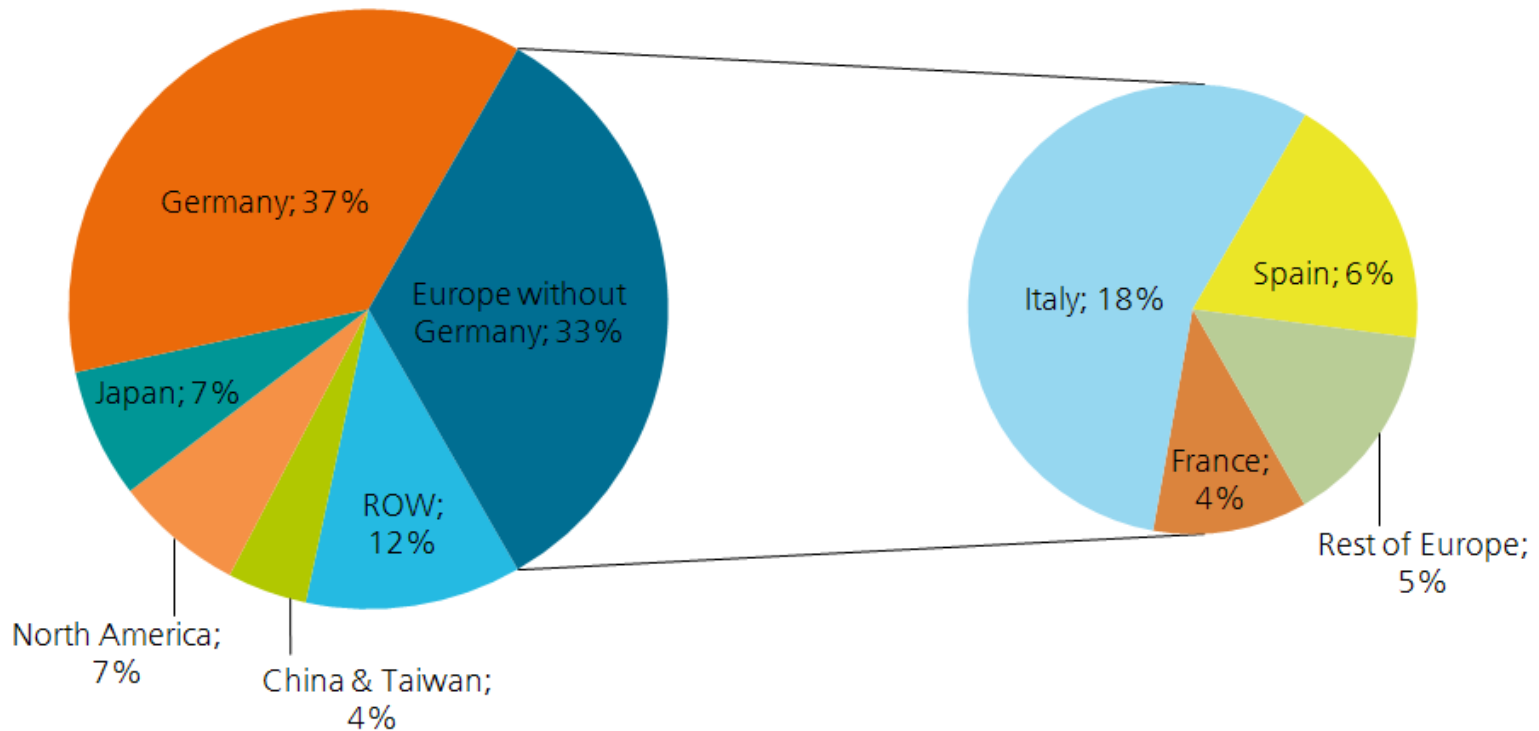
PV Industry Production by Region (2000-2011)



Data: Navigant Consulting Graph: PSE AG 2012

Global Cumulative PV Installation until 2011

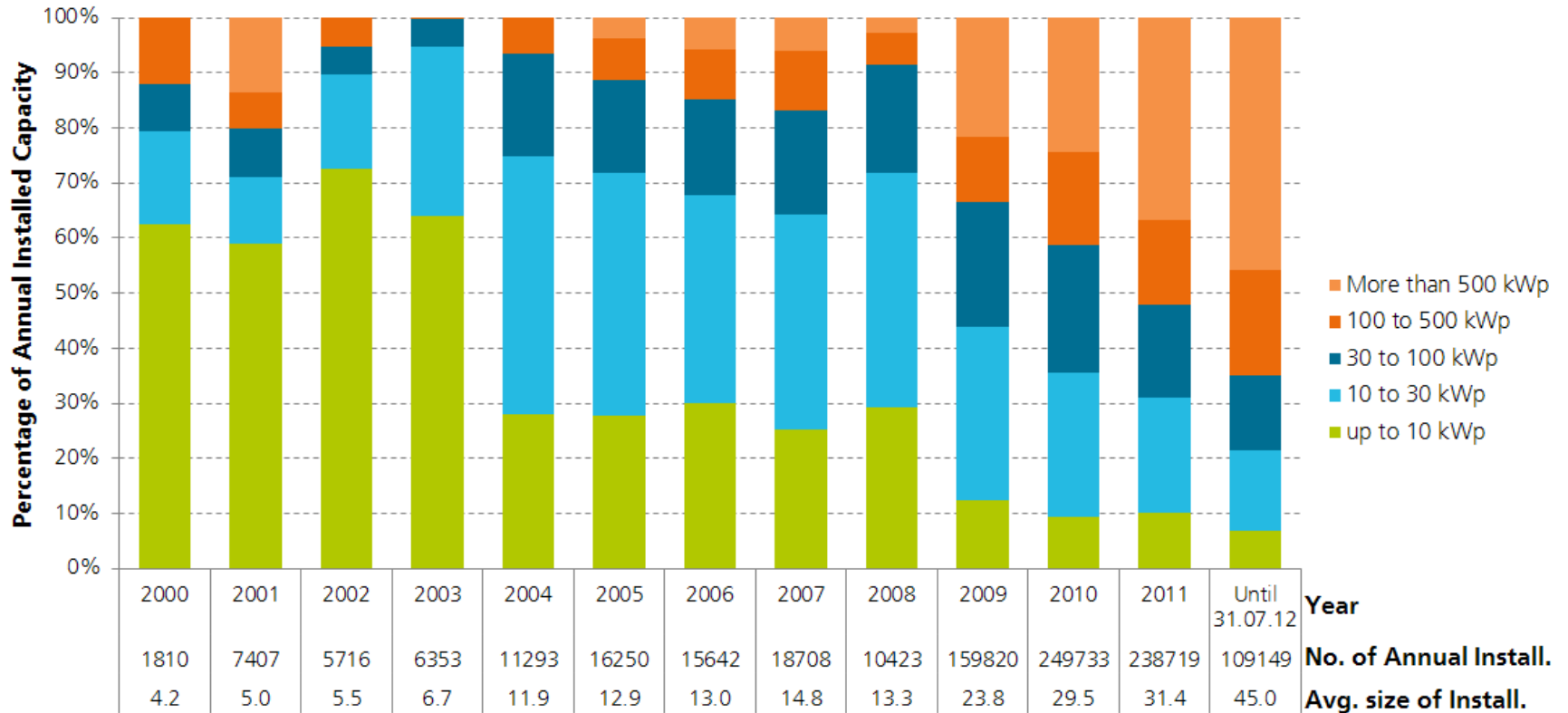
All percentages are related to the total global installation



Data: EPIA Graph: PSE AG 2012

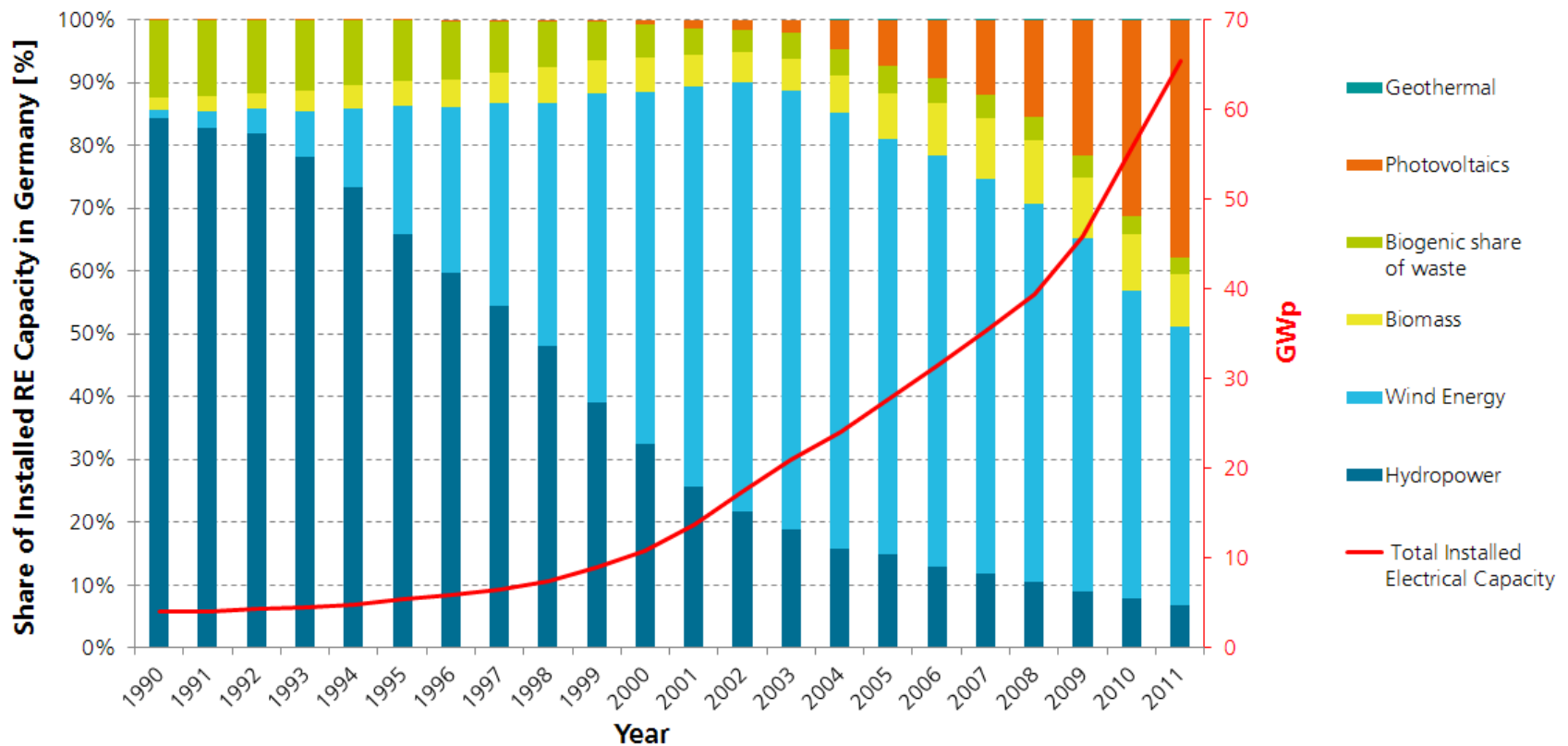
PV Systems Yearly Installed in Germany

Shares by System Size



Data: up to 2008: utilities (may not be complete); since 2009: Bundesnetzagentur Graph: PSE AG 2012

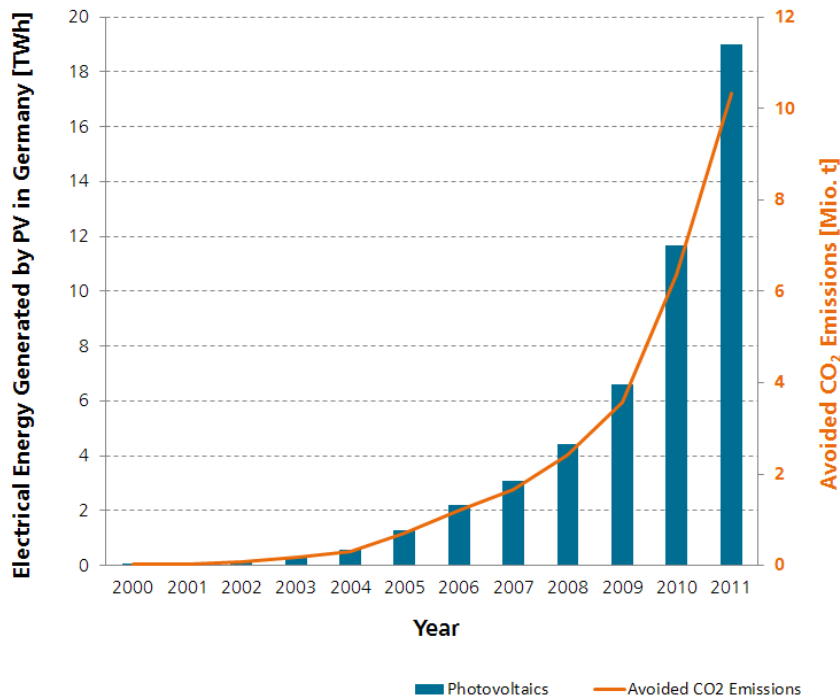
Electrical Capacity of Renewable Energy Sources in Germany



In 2011 about 20% of the electricity in Germany has been generated by renewable energy (RE) sources according to BDEW

Data: BMU, BDEW Graph: PSE AG 2012

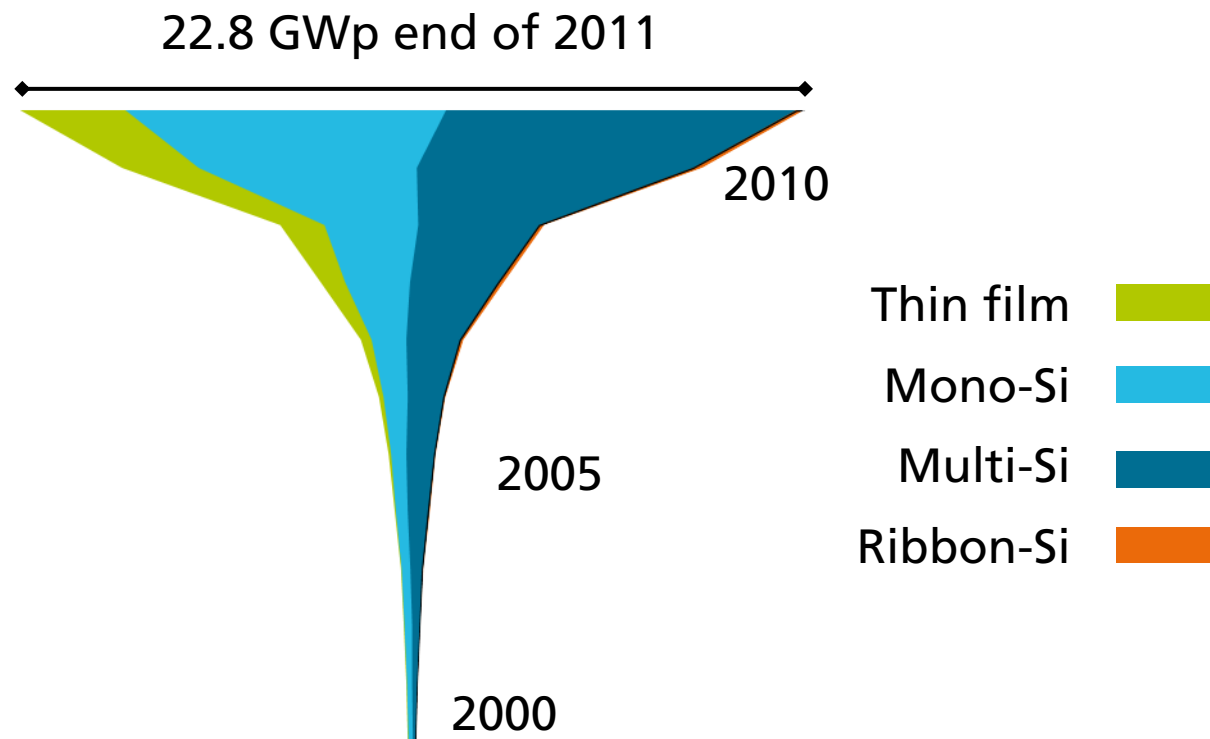
PV Energy Generated in Germany and the Resulting CO₂ avoided Emissions



- In 2011 about 10 Mio. t CO₂ emissions have been avoided due to 19 TWh electrical energy generated by PV in Germany.
- German electricity generation mix 2010: For each kWh of electricity generated, 544 grams of CO₂ are emitted.

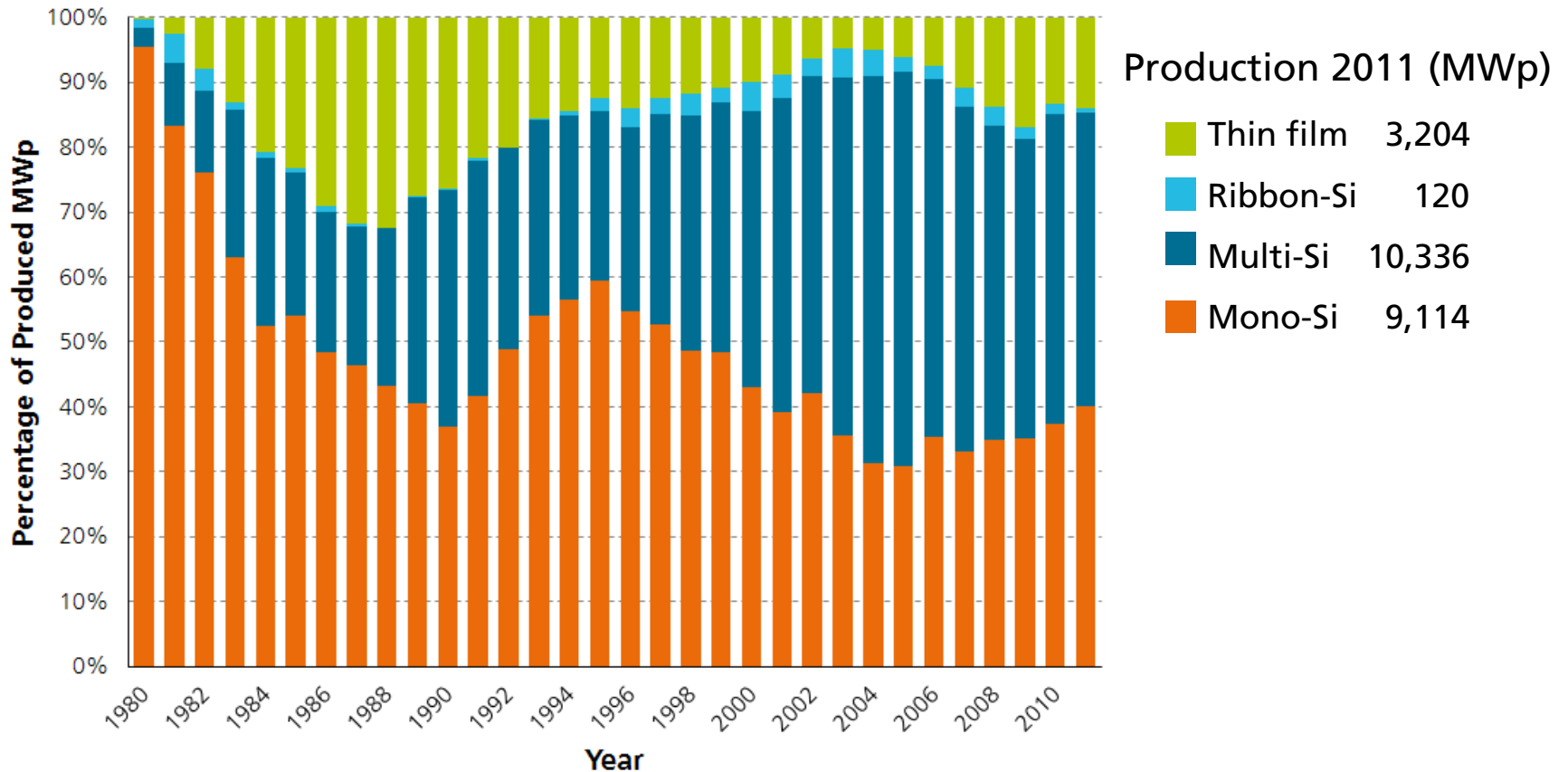
Data: BMU, BDEW, UBA 2012; Graph: PSE AG 2012

Global Annual PV Installation by Technology



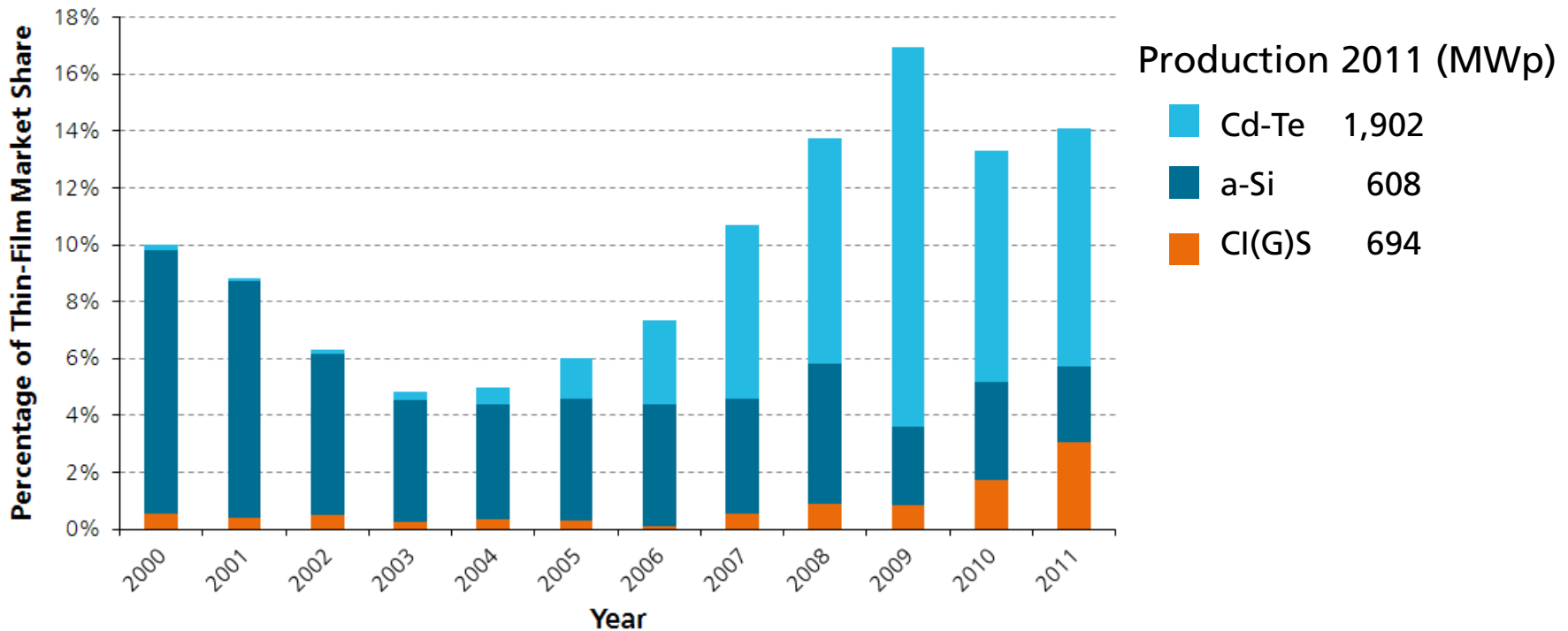
Data: Navigant Consulting Graph: PSE AG 2012

PV Production Development by Technology



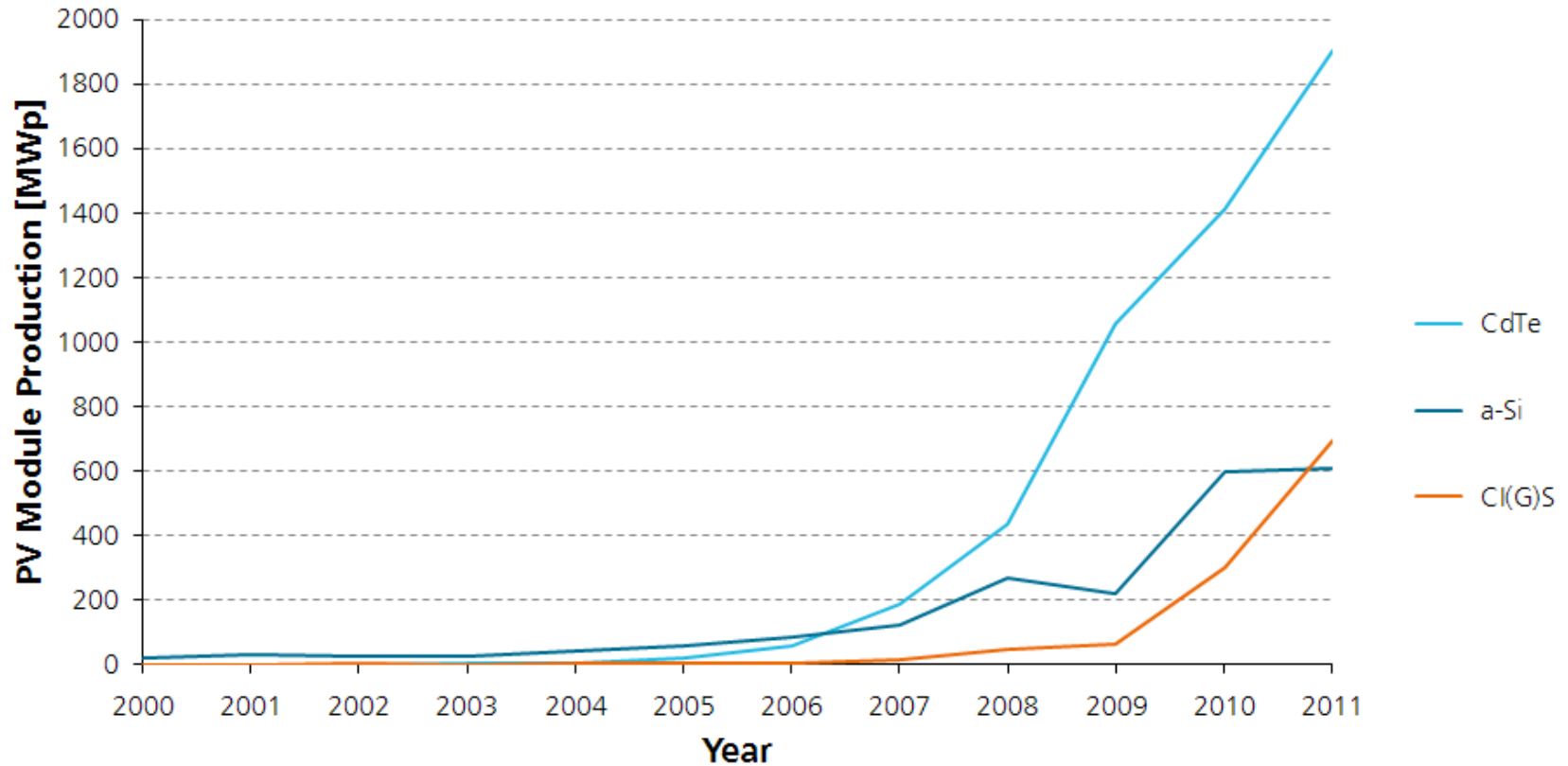
Data: Navigant Consulting Graph: PSE AG 2012

Market Share of Thin-Film Technologies Related to Total Worldwide PV Production



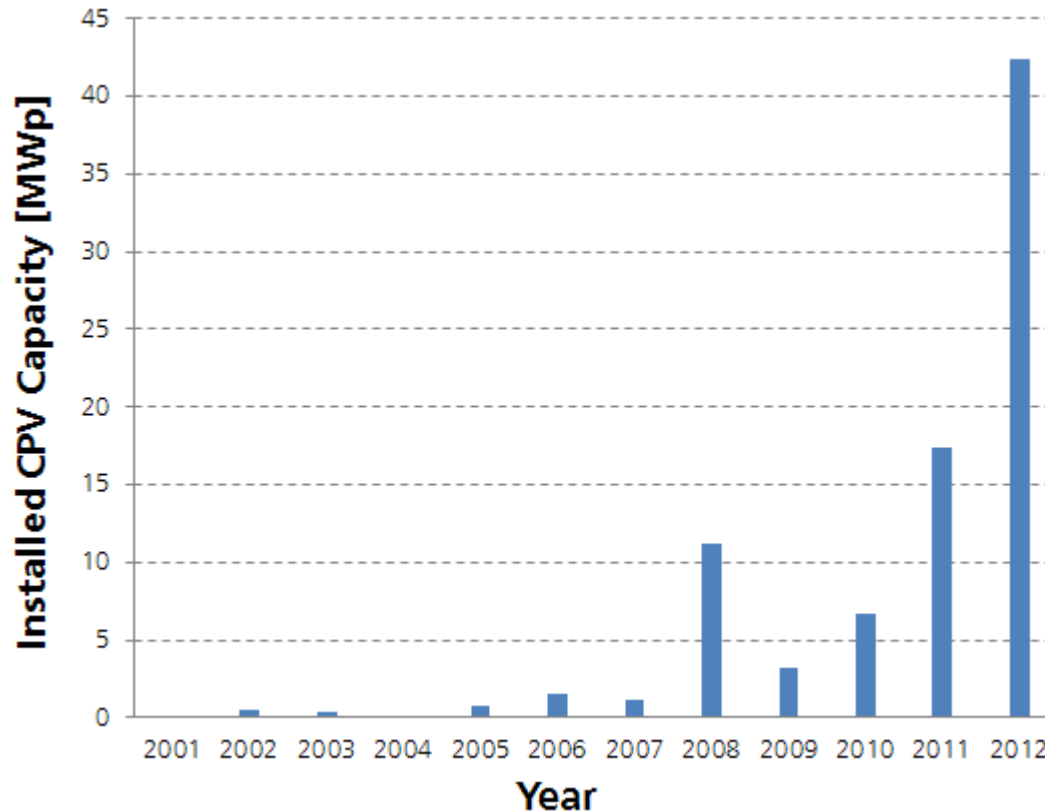
Data: Navigant Consulting Graph: PSE AG 2012

Thin-Film Technologies Worldwide Annual PV Module Production in MWp



Data: Navigant Consulting Graph: PSE AG 2012

Yearly Installed Capacity of High Concentration Photovoltaic Systems (HCPV)*



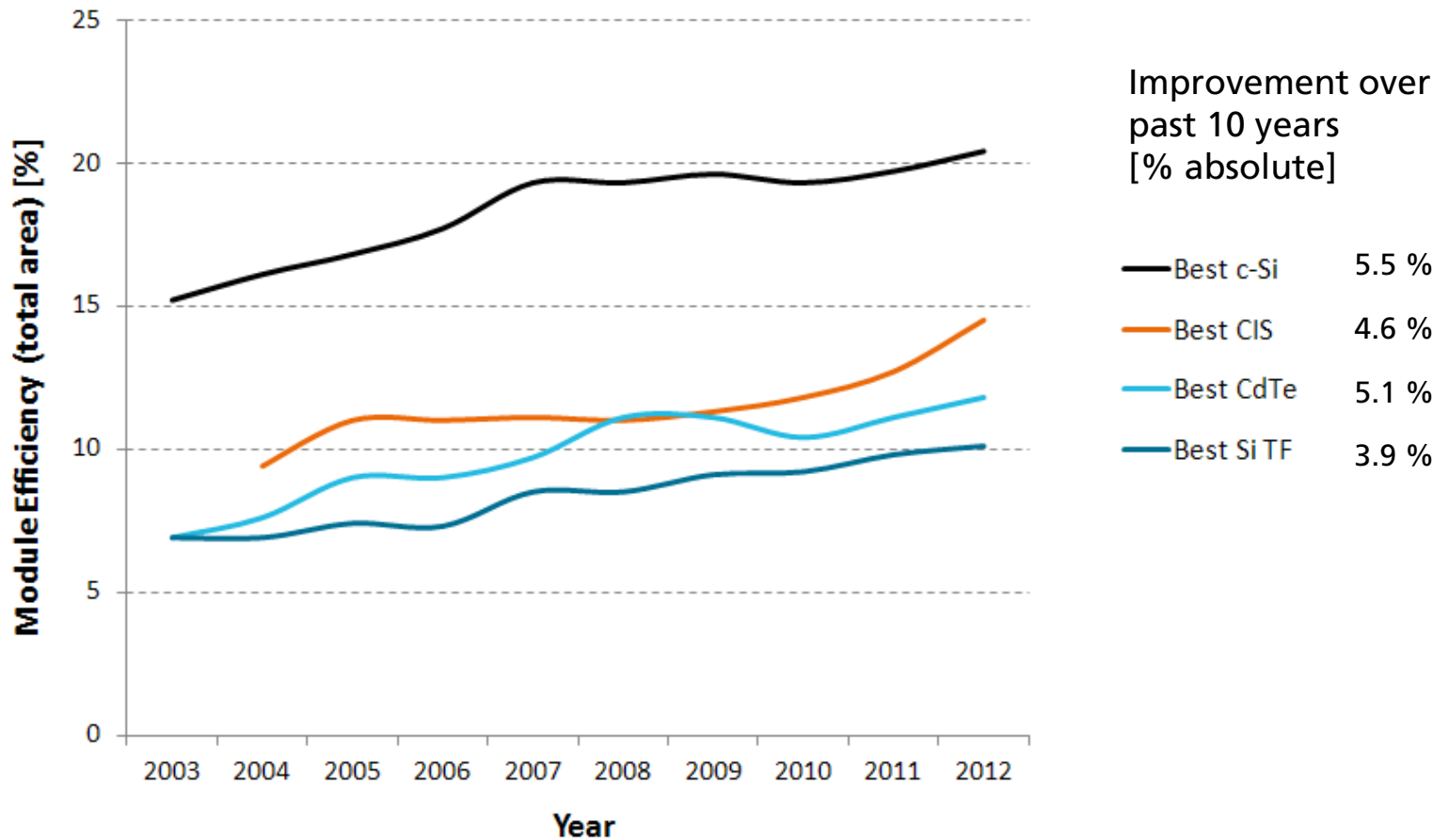
*HCPV has concentration factor from 300 up to 1000 suns

Data: ISE 2012 Graph: PSE AG 2012

2. Solar Cells / Modules / System Efficiency

- Development in the PV Industry
- Development in the Laboratories
- High Concentration Photovoltaics (HCPV)
- Performance Ratio (PR)

Industrial PV Module Efficiency [%] – Best Modules



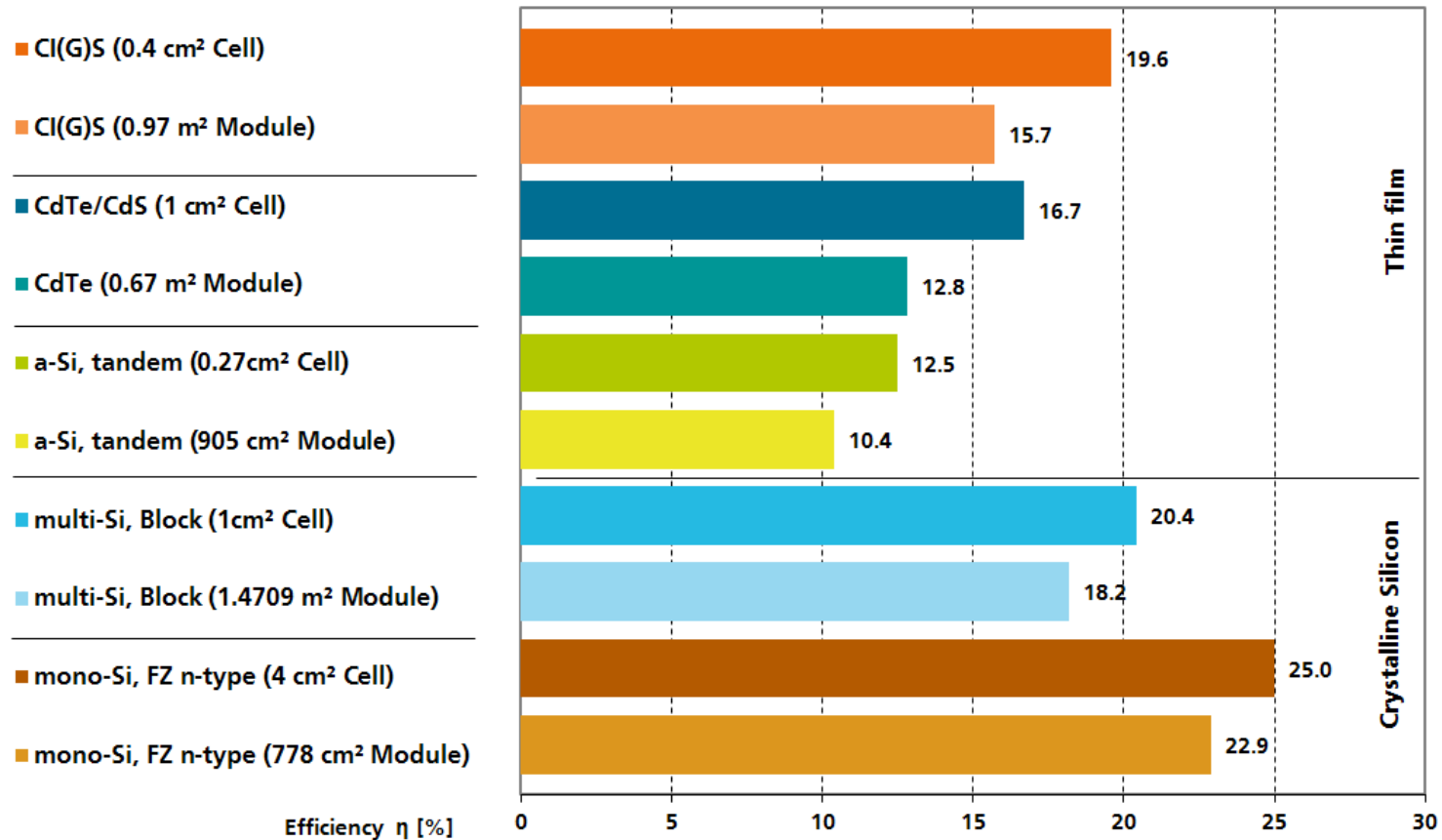
Data: Photon 2/2003-2009, Photon Profi 2/2010-2/2012, Graph: Willeke Fraunhofer ISE 2012

Industrial PV Module Efficiency [%] – Average Modules



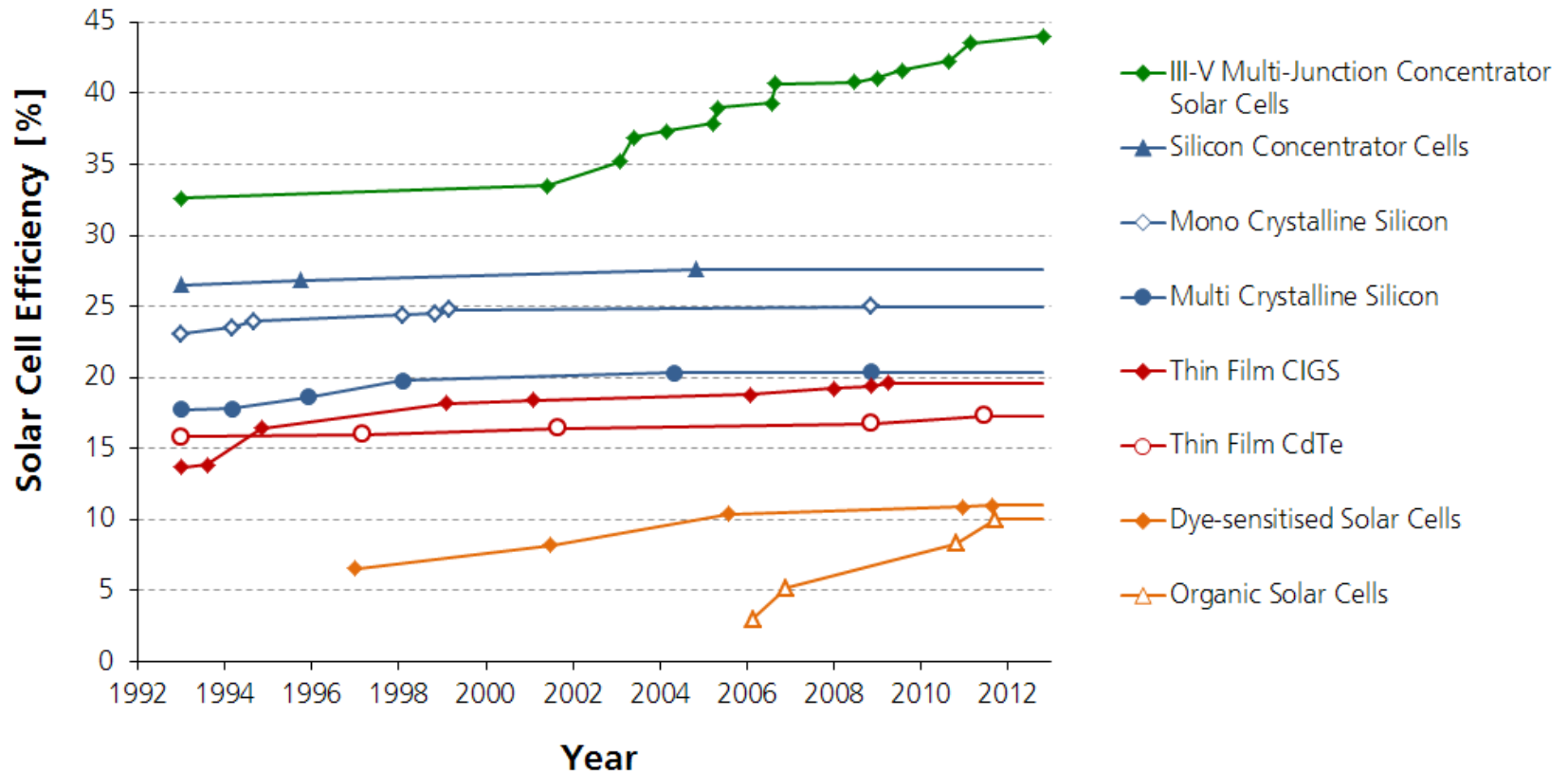
Data: Photon 2/2003-2009, Photon Profi 2/2010-2/2012, Graph: Willeke Fraunhofer ISE 2012

Efficiency Comparison of Technologies: Best Lab Cells vs. Best Lab Modules



Data: Green et al.: Solar Cell Efficiency Tables,(Version 1-40), Progress in PV: Research and Applications 2012, Graph: PSE AG 2012

Development of Laboratory Solar Cell Efficiencies



Data: Solar Cell Efficiency Tables (Verions 1-40), Progress in PV: Research and Applications, 1993-2012, Graph: Simon Philipps, Fraunhofer ISE

High Concentration Photovoltaics (HCPV) Specific Aspects and Efficiencies

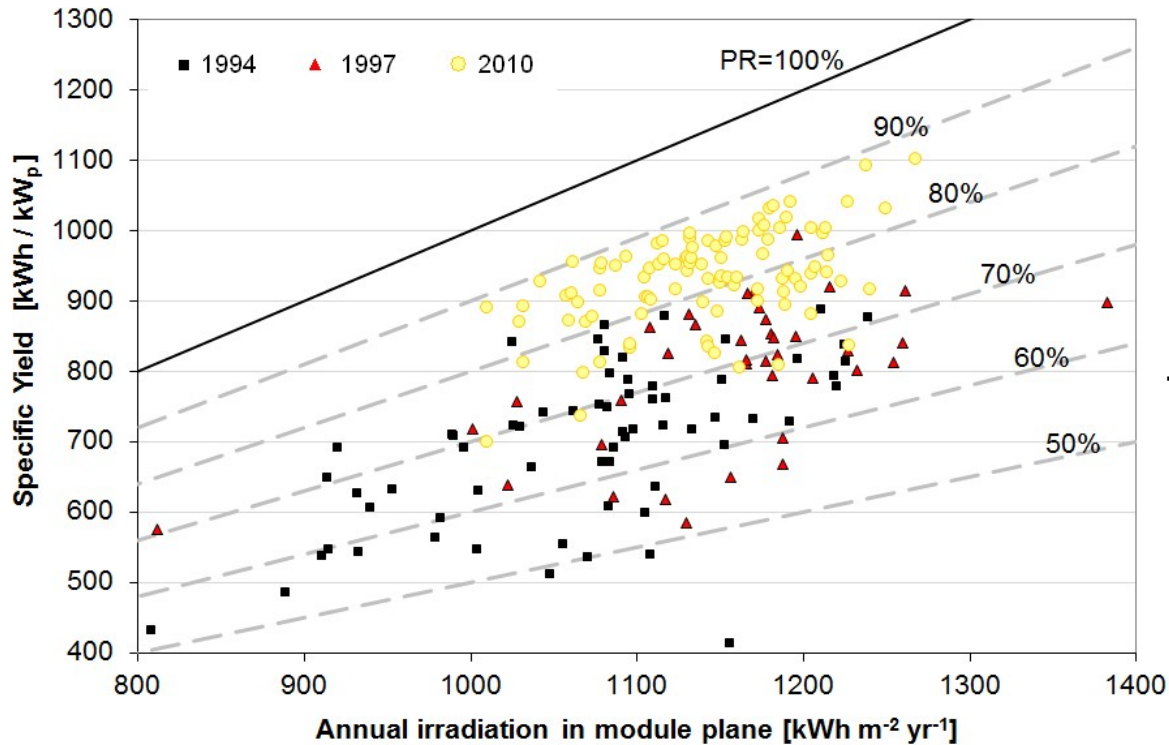
- HCPV is suitable for areas with high direct normal irradiance
- Concentrating optics are used to focus the light on small solar cells
- Concentration levels above 400 suns have become standard
- Various designs of HCPV systems are commercially available
- High efficiencies are achieved (see table)



Efficiencies	Lab Record	Commercial
Solar Cell	43.5 % (Solar Junction)	37-40%
Module	33.9% (Semprius)	25-31%
System (AC)	N.A.	23-27%

Source: Fraunhofer ISE, Progress in Photovoltaics, Semprius 2012

Performance Ratio Development of PV Systems in Germany



In the 1990's

- Typical PR ~70 %
- Very wide PR-range

Today

- Typical PR ~80-90 %
- Less variance in PR as compared to 1990's

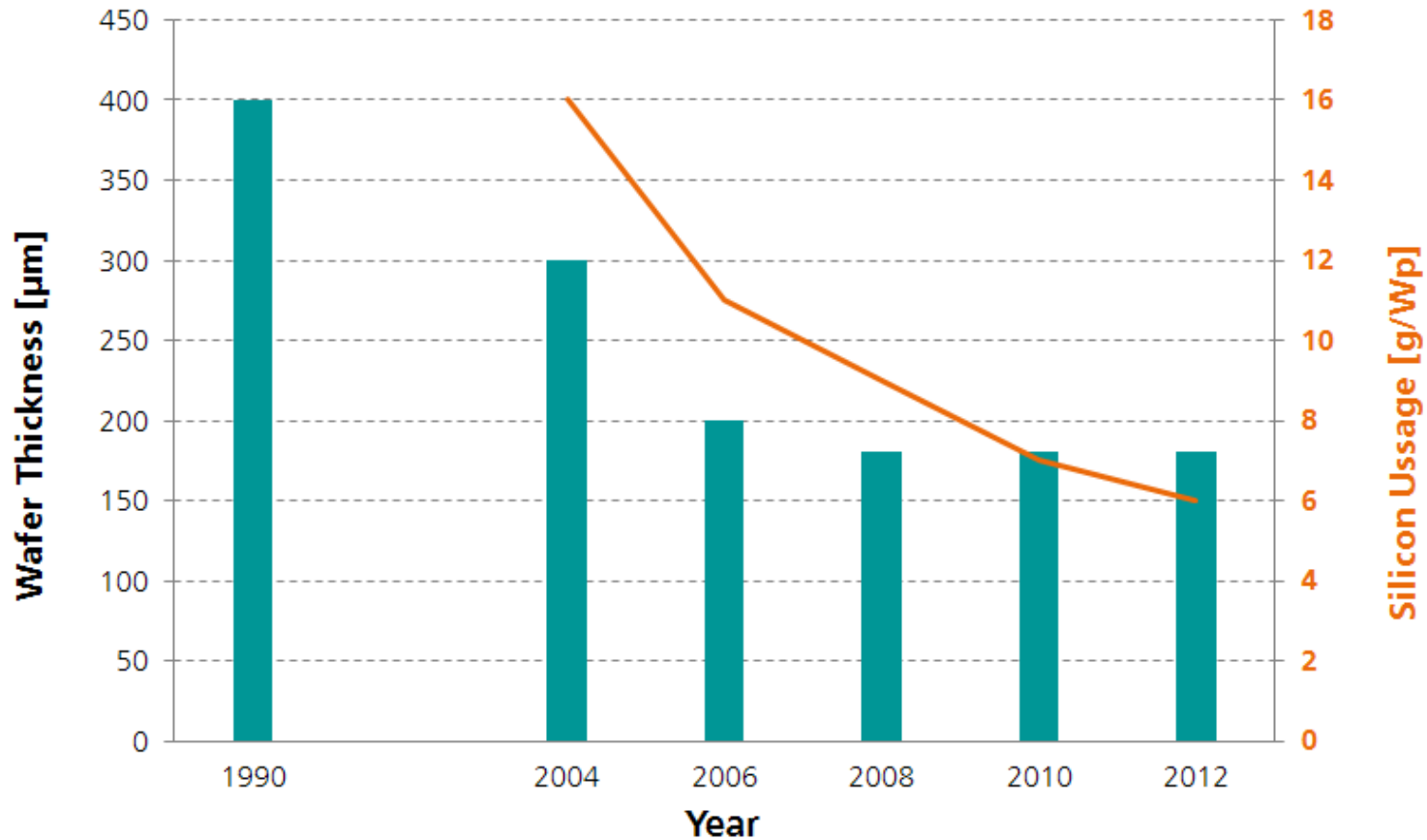
Source: Fraunhofer ISE "1000 Dächer Jahresbericht" 1994 and 1997; 2011 system evaluation

3. Energy Payback Time (EPBT)

- Silicon usage, wafer thickness and kerf loss for c-Si
- EPBT: Development and comparison

C-Si Solar Cell Development

Wafer Thickness [μm] & Silicon Usage [g/Wp]



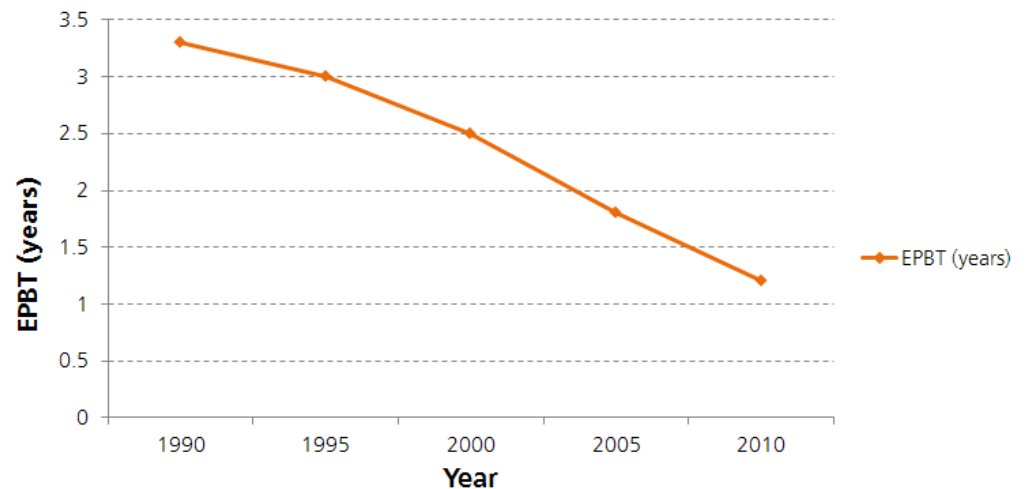
Data: until 2010, EU PV Technology Platform Strategic Research Agenda, c-Si Roadmap ITPV, EPIA roadmap 2004; for 2012: Fraunhofer ISE Graph: PSE AG 2012

Historic Trend in Energy Payback Time of Crystalline Silicon PV Modules

Depending on the type and location of the PV system, the EPBT presently lies between 0.5 and 1.4 years

The technical lifetime of PV systems is 30+ years; hence they produce net clean electricity for more than 95 % of their lifetime.

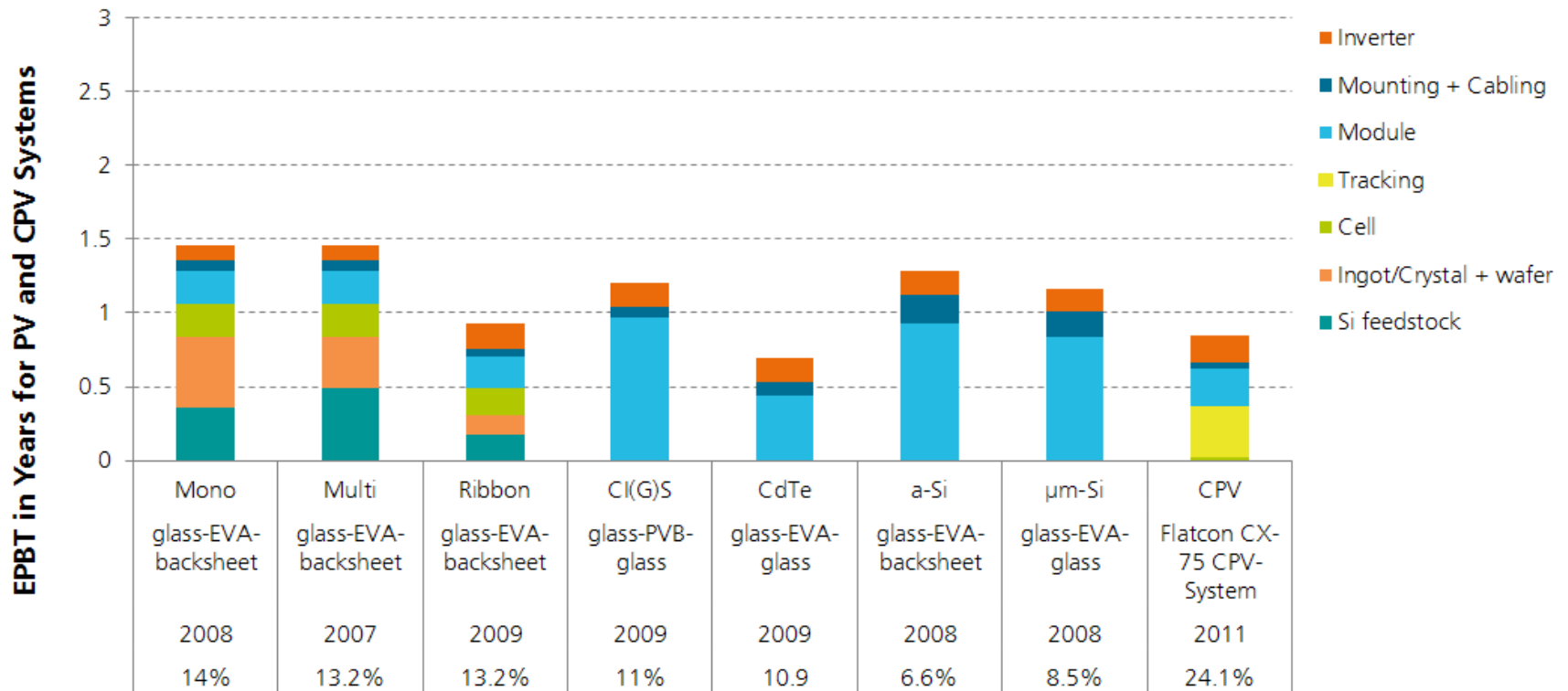
Rooftop Installations in Southern Europe (1700 kWh/m²/a)



Data: EPIA Sustainability Working Group Fact Sheet 2011, Graph: PSE AG 2012

Energy Pay-Back Time for PV and CPV Systems from different Technologies in Catania, Sicily, Italy

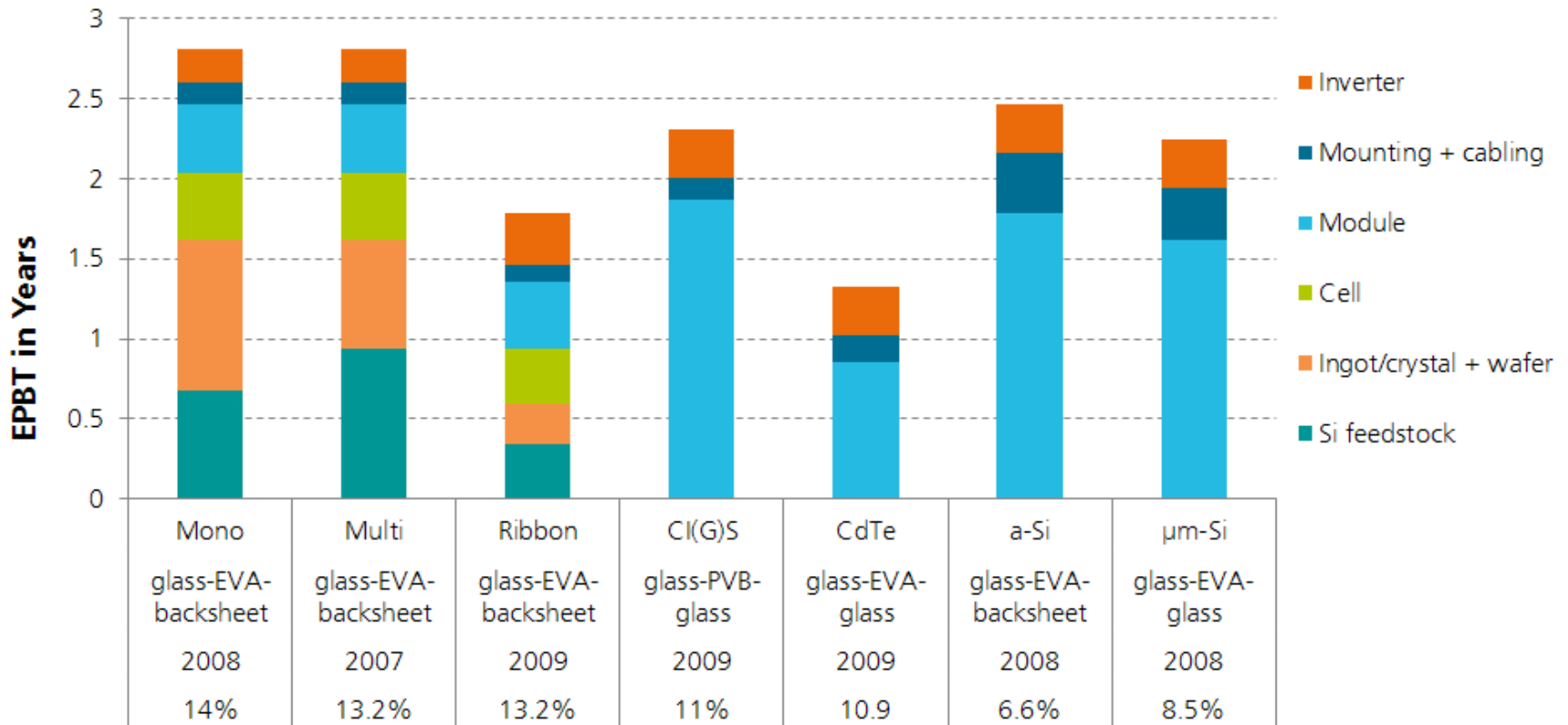
Global Irrad.: 1925 kWh/m²/yr, Direct Normal Irrad.: 1794 kWh/m²/yr



Data: Mono- and multi-Silicon data: ISE 2011; CPV data: "Environmental Sustainability of Concentrator PV Systems: Preliminary LCA Results of the Apollon Project" 5th World Conference on PV Energy Conversion. Valencia, Spain, 6-10 September 2010; all other data: Wild-Scholten (ECN), Sustainability Dec. 2009., Graph: PSE AG 2012

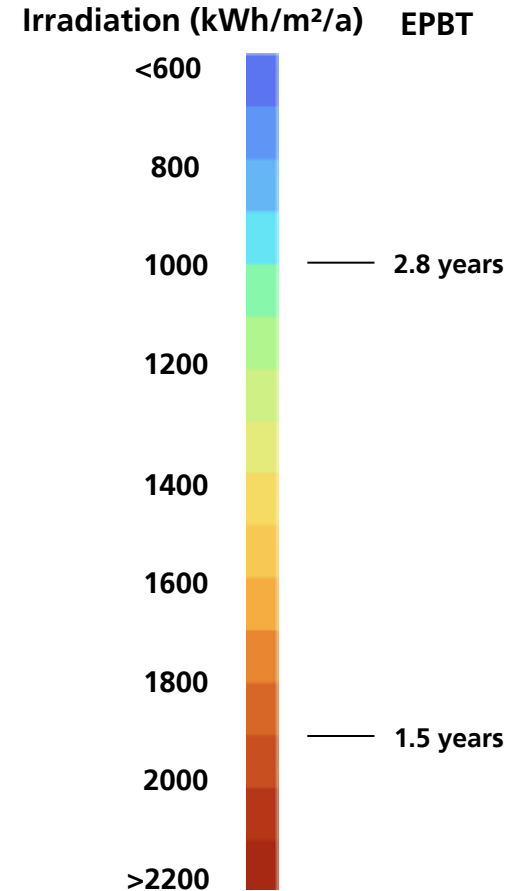
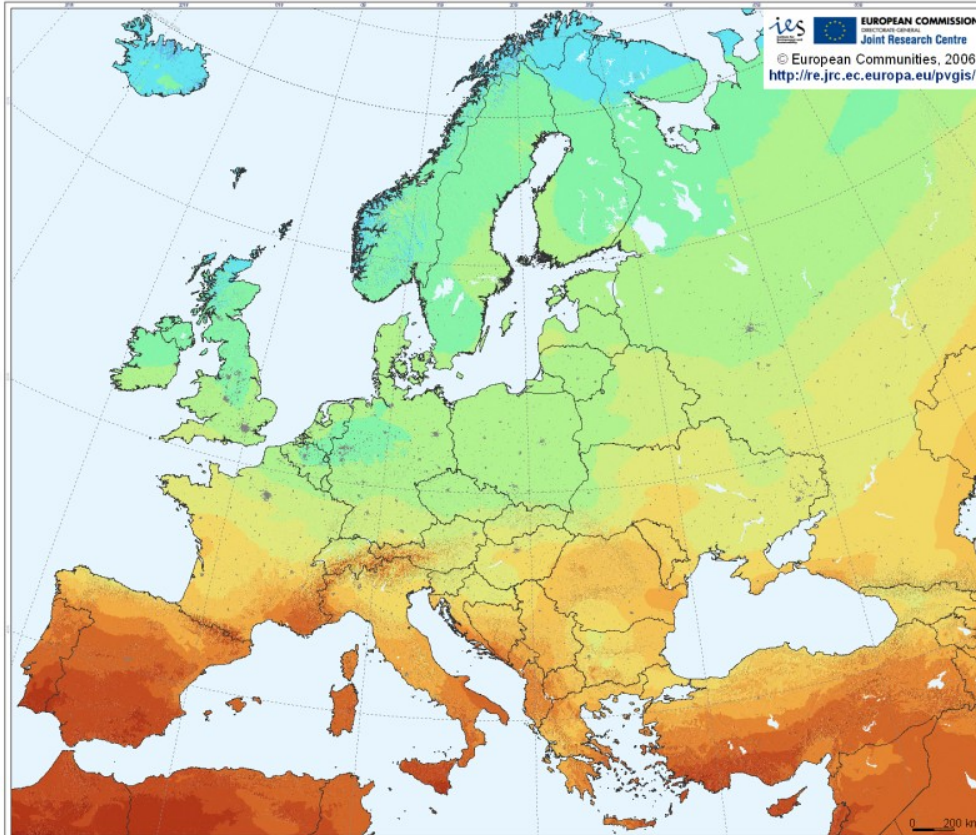
Energy Pay-Back Time of Rooftop PV Systems from different Technologies in Germany

Global Irrad.: 1000 kWh/m²/yr



Data: ISE 2011 (for mono, multi); de Wild-Scholten (ECN), Sustainability Dec. 2009, Graph: PSE AG 2012

Energy Pay-Back Time of Multicrystalline Silicon PV Systems - Geographical Comparison



Data: Image provided by JRC European Commission, Graph: PSE AG 2012 (Modified scale with updated data from PSE AG and Fraunhofer ISE)

4. Inverters

- Inverter/Converter Price
- Inverter Concept Comparison

Inverter/Converter Market

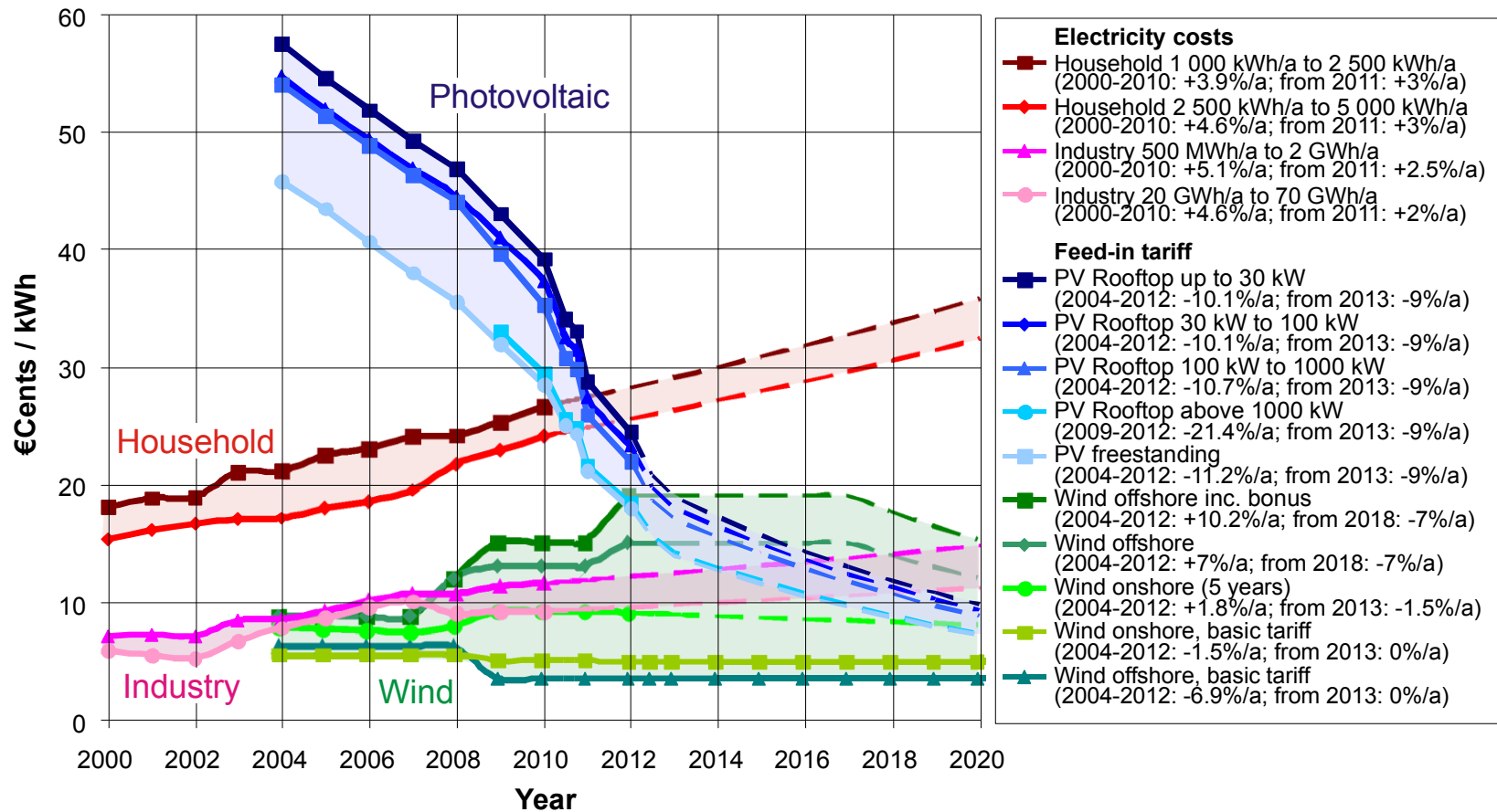
Inverter / Converter	Power	Efficiency	Market Share (Estimated)	Remarks
String Inverters	Up to 100 MWp	98%	90%	<ul style="list-style-type: none"> • 20-30 €-cents/Wp • Easy to replace
Central Inverters	More than 100MWp	Up to 98.5%	9%	<ul style="list-style-type: none"> • 20-25 €-cents/Wp • High reliability • Often sold only together with service contract
Micro-Inverters	Module Power Range	90%-95%	<1%	<ul style="list-style-type: none"> • 50-80€-cents /Wp • Ease-of-replacement concerns
DC/DC Converters (Power Optimizer)	Module Power Range	Up to 98.8%	~ 0.3%	<ul style="list-style-type: none"> • Average 40-80 €-cents/Wp • Ease-of-replacement concerns • Today 4 producer each with about 20 MWp annual production. • Output is DC with optimized current

Data: Paula Mints (Navigant Consulting) 2011; SolarEdge 2012, Fraunhofer ISE 2011, Graph: PSE AG 2012

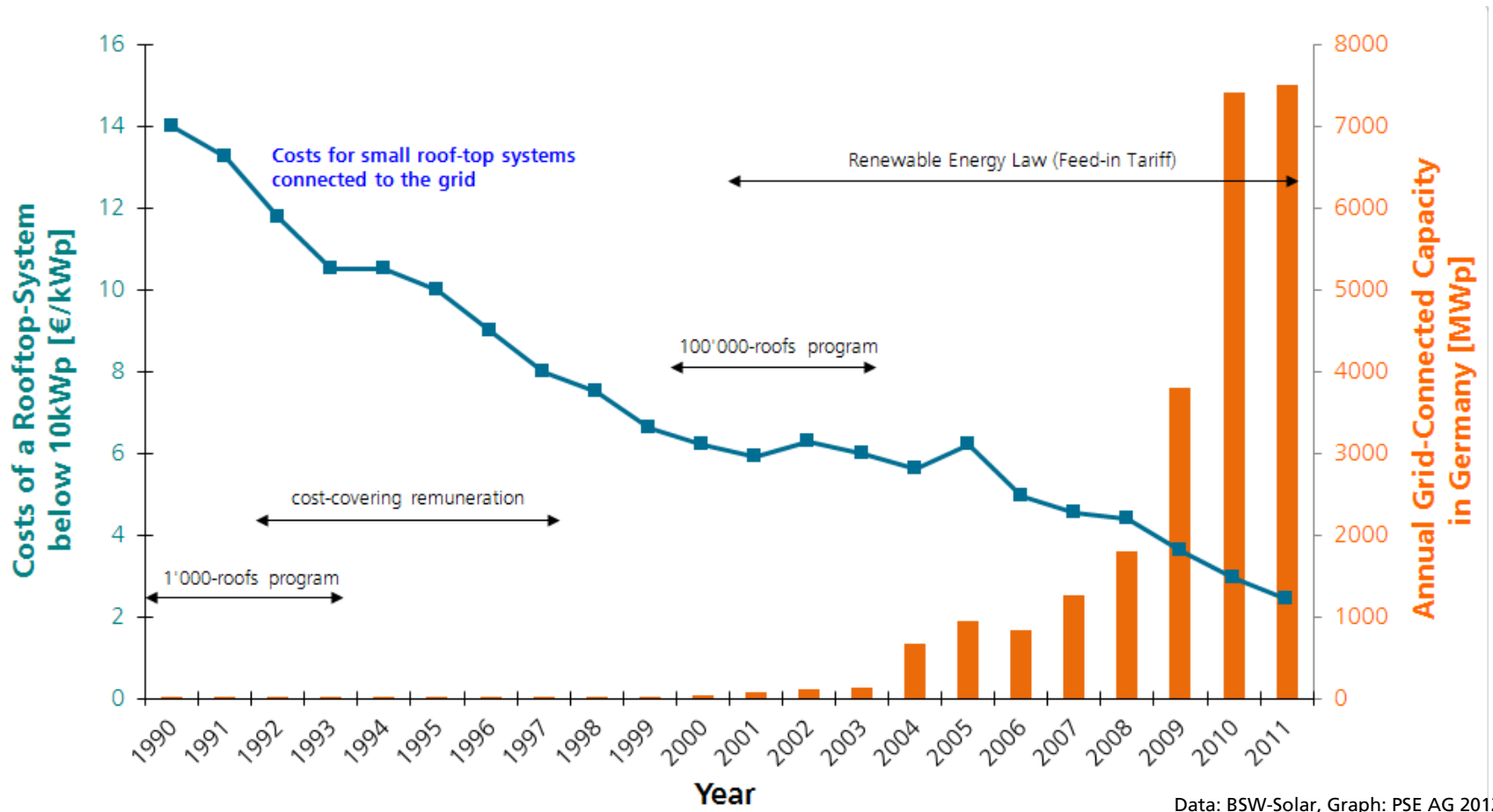
5. Price Development

- Electricity costs
- Costs for rooftop systems
- Market incentives in Germany
- Price Learning Curve

Electricity Costs and Feed-In Tariffs in Germany

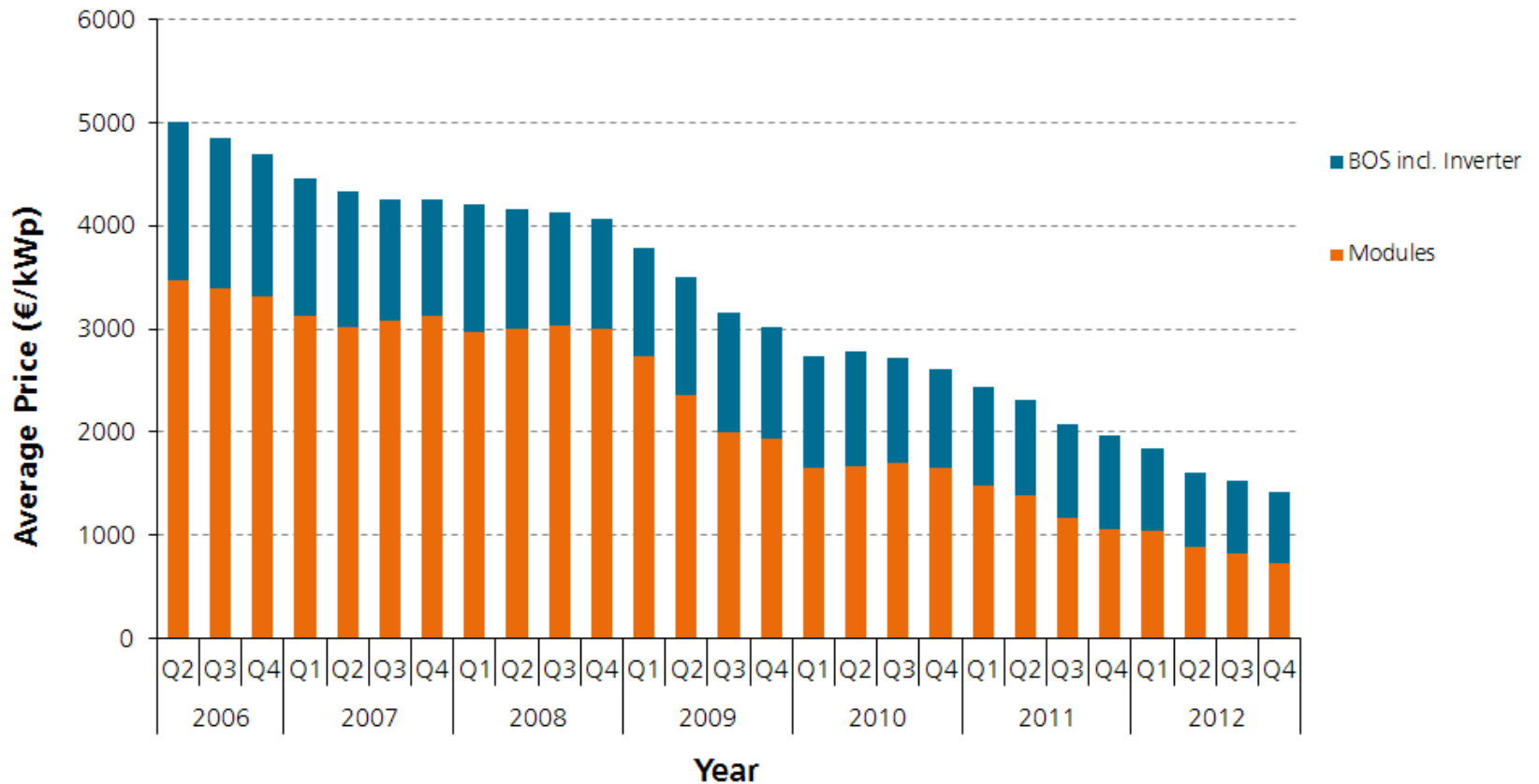


Investment for Small Rooftop PV Systems in Relation to Market Development and Subsidy Schemes in Germany



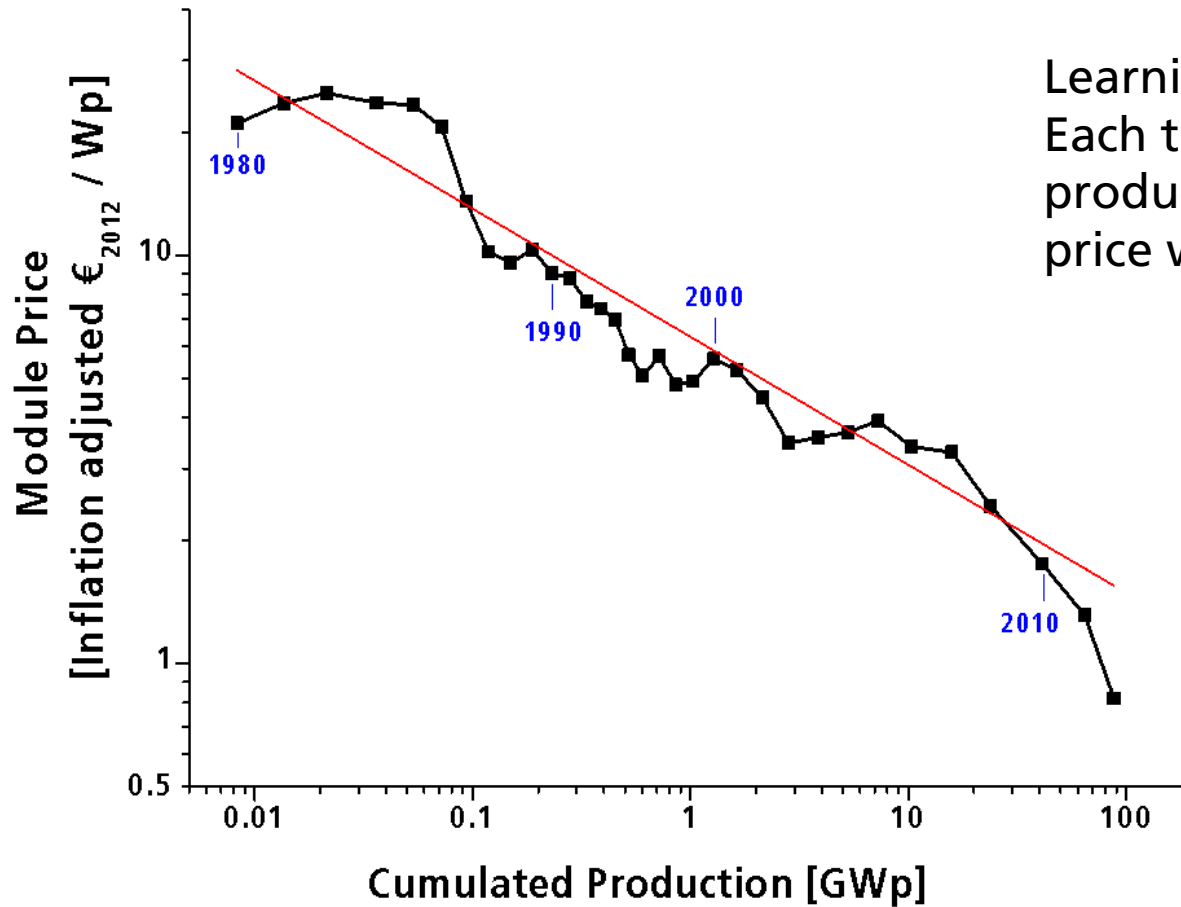
Data: BSW-Solar, Graph: PSE AG 2012

Average Price for PV Rooftop Systems in Germany (10kWp - 100kWp)



Data: BSW-Solar, Graph: PSE AG 2012

Price Learning Curve (all bulk PV Technologies)

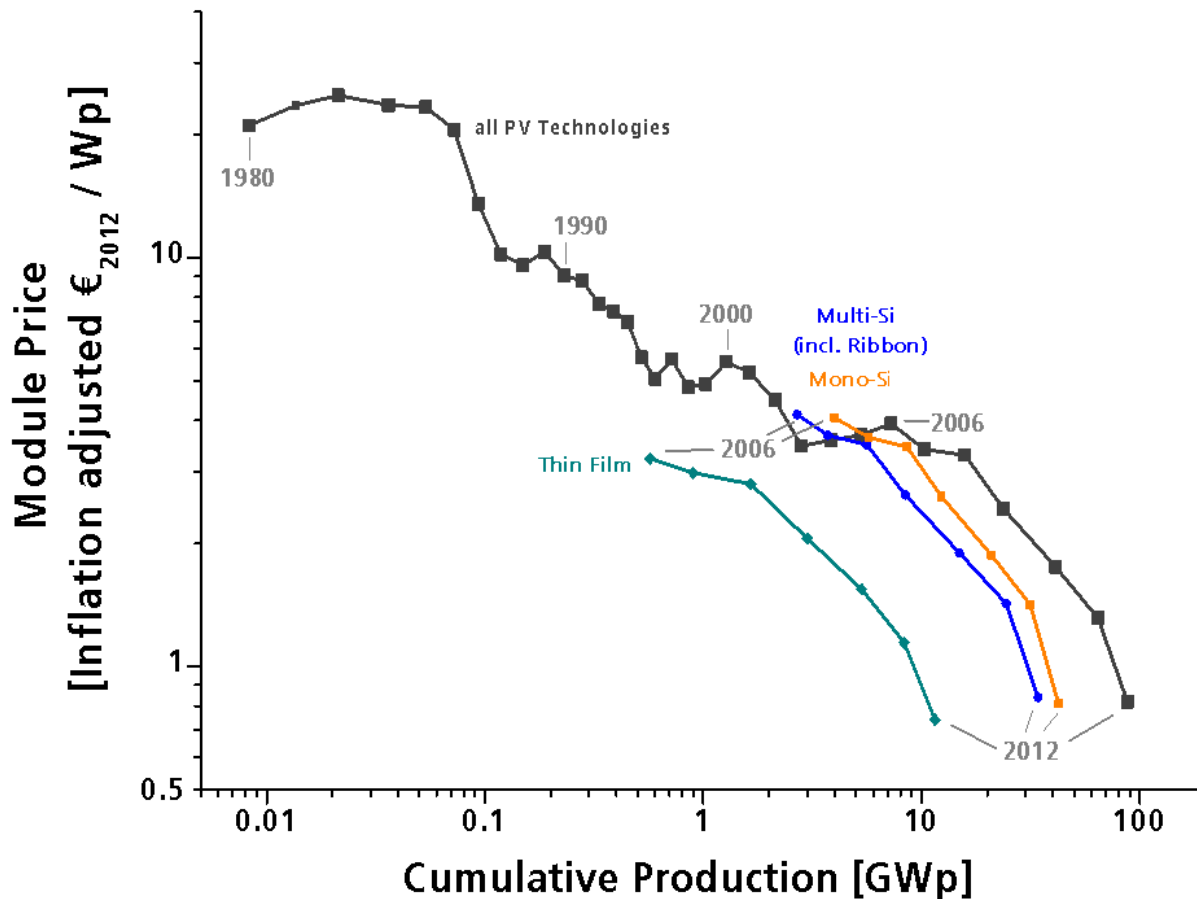


Learning Rate:
Each time the cumulative
production doubled, the
price went down by 19.6 %

Data: Navigant Consulting; EUPD module price (since 2006) Graph: PSE AG 2012

Price Learning Curve by Technology

Cumulative Production up to 2012



- All PV Technologies
- Mono-Si 34.2 GWp
- Multi-Si 42.5 GWp
(incl. Ribbon-Si)
- ◆ Thin Film 11.5 GWp

all PV Technol. (1980-2012) **LR 19.6**
 all PV Technol. (2006-2012) **LR 29.2**
 Mono (2006-2012) **LR 29**
 Multi (2006-2012) **LR 30.1**
 Thin Film (2006-2012) **LR 22.8**

Data: Navigant Consulting; EUPD module price (since 2006) Graph: PSE AG 2012

Acknowledgements

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