Energy research Centre of the Netherlands

# Photovoltaic solar energy

*progress beyond expectations*


Wim Sinke

ECN Solar Energy & European Photovoltaic Technology Platform


# Contents



*Background photo: www.bso.vvs.be*

## Contents

**The PV challenges quantified**

**Building blocks for the solution**

- technology portfolio & system approaches

**Economics and markets**

- state of the art and projections

**R&D priorities**

**Crossing the valleys of death**

- from incentive-driven to self-sustained markets
- from technology push to market pull

**Outlook**

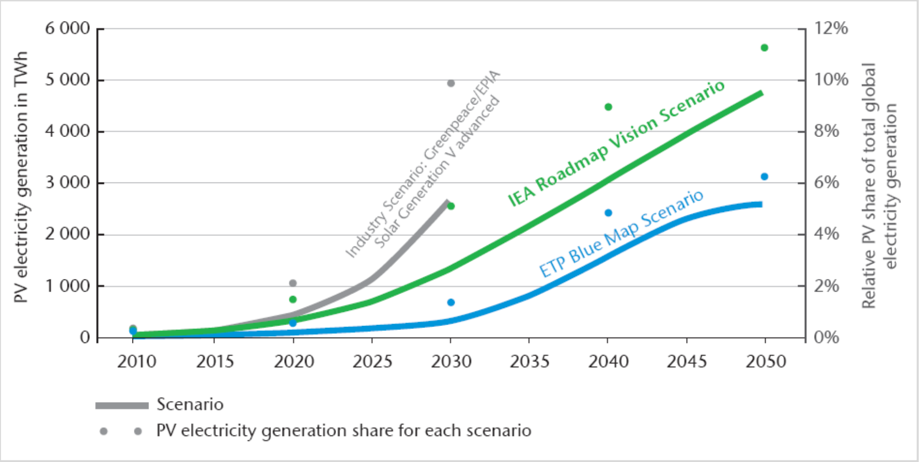
*Background photo: www.bso.vvs.be*

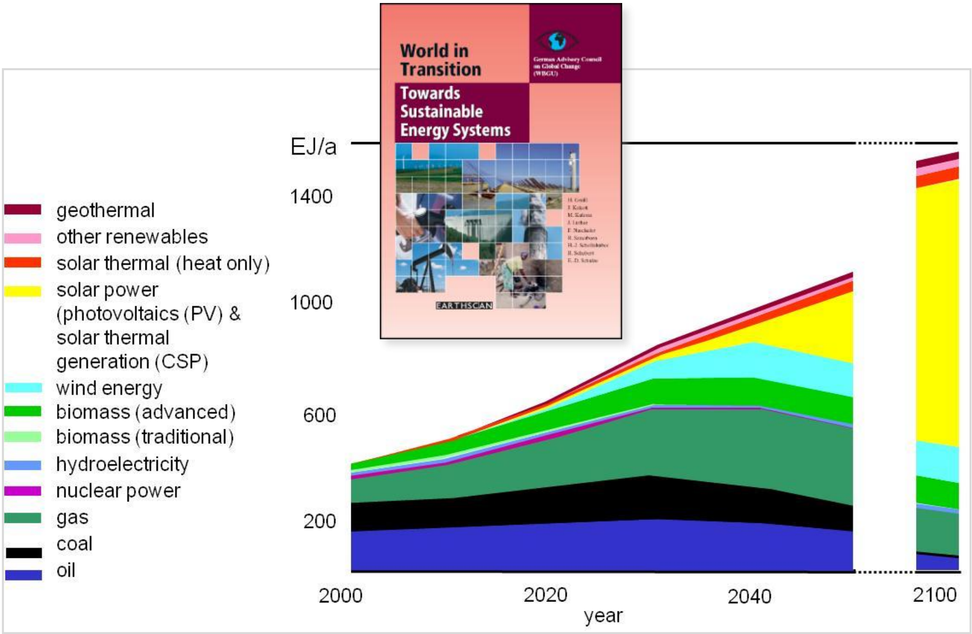
# The challenge quantified

- How much is needed for impact?
- At what cost?
- Under which conditions?

# How much is needed for impact?

## From 10% global *electricity* to >25% of global *energy*:




**3 ~ >30 TWp**

*(now 0.05 TWp)*

# At what cost (price)?

**0.05 $/kWh ~ 0.10 €/kWh** *(or less)*

# From generation cost to system price (or back)
# *not a trivial exercise*

***Levelized Cost of Electricity (LCoE) determined by:***

turn-key system price ($/Wp)

- module price + Balance-of-System price
  *(power-related part & area-related part)*

energy output (kWh/Wp·yr)

- primarily dependent on annual insolation
- influenced by system quality and design, partial shading, etc.

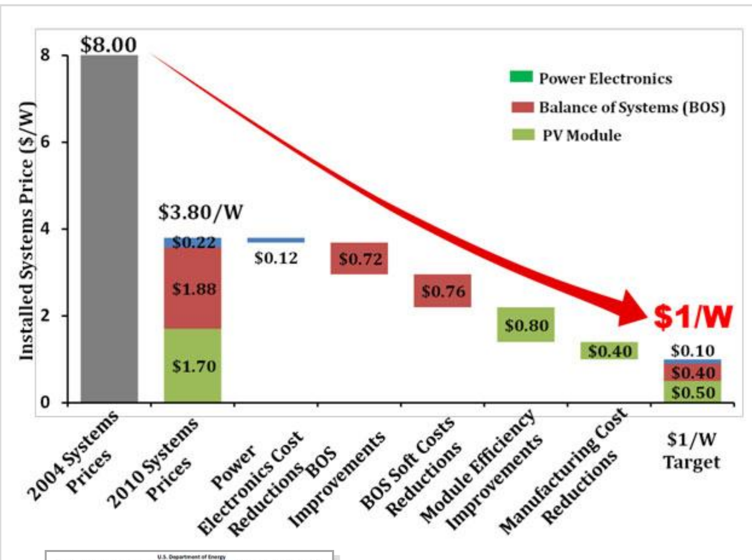
operation & maintenance cost and replacement/repair ($/Wp·yr)

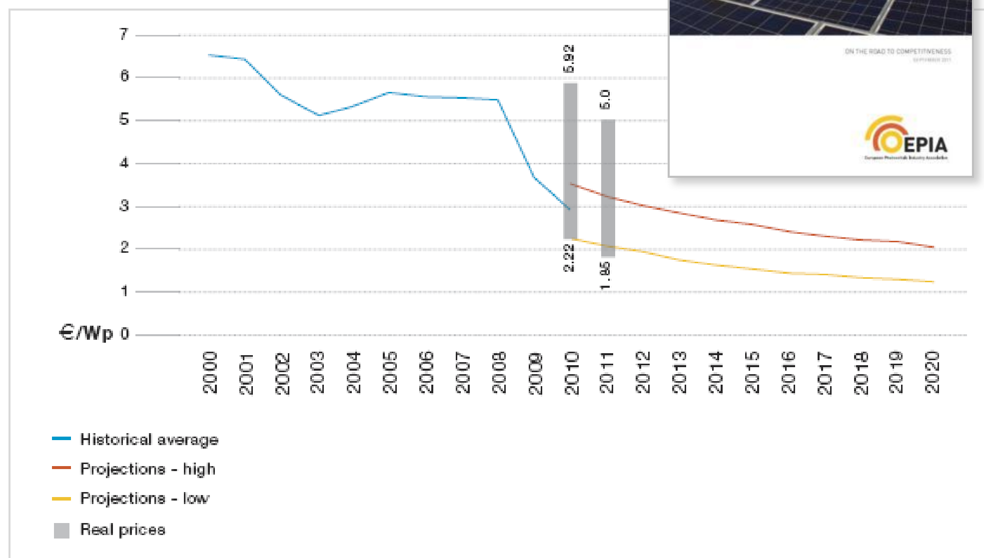
cost of capital:

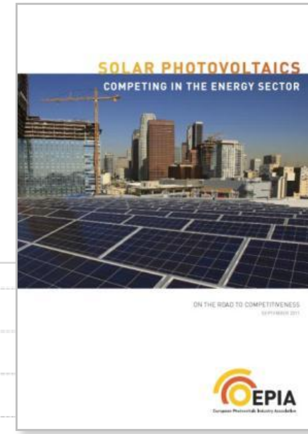
- depreciation time (yr)
- interest rate / Return on Investment required (%)

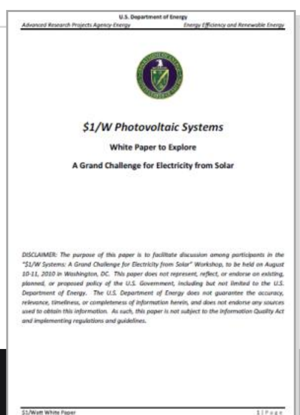
# At what cost (price)?

## 0.05 $/kWh ~ 0.10 €/kWh *(or less)*:



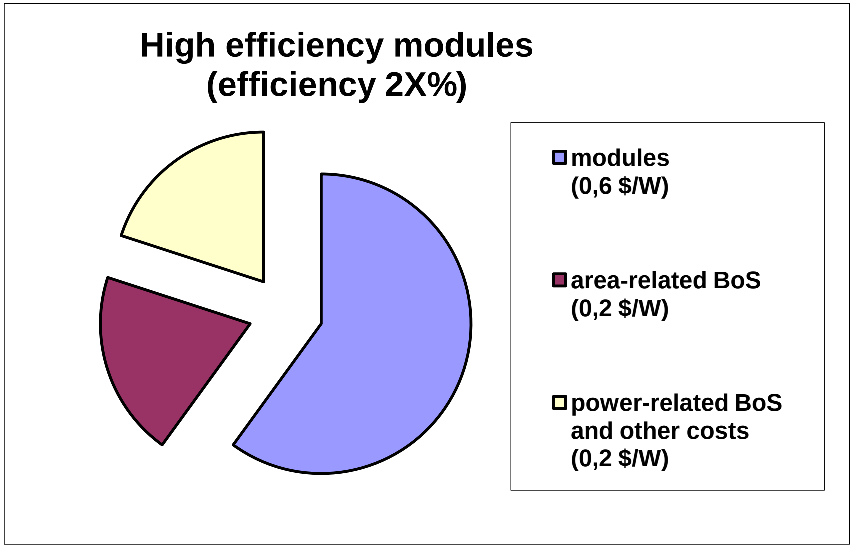



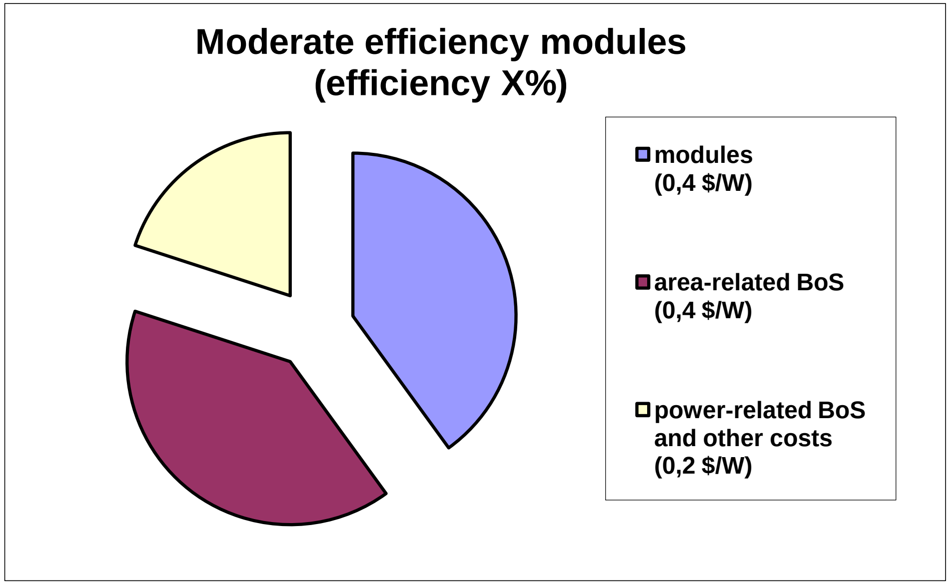

*typically*

**1 $(€)/Wp**

*(now ≥2 € /Wp)*

# At what cost (price)?
## *The value of efficiency (example)*




**turn-key system price 1 $/Wp**

# Under which conditions?

## Sustainability:

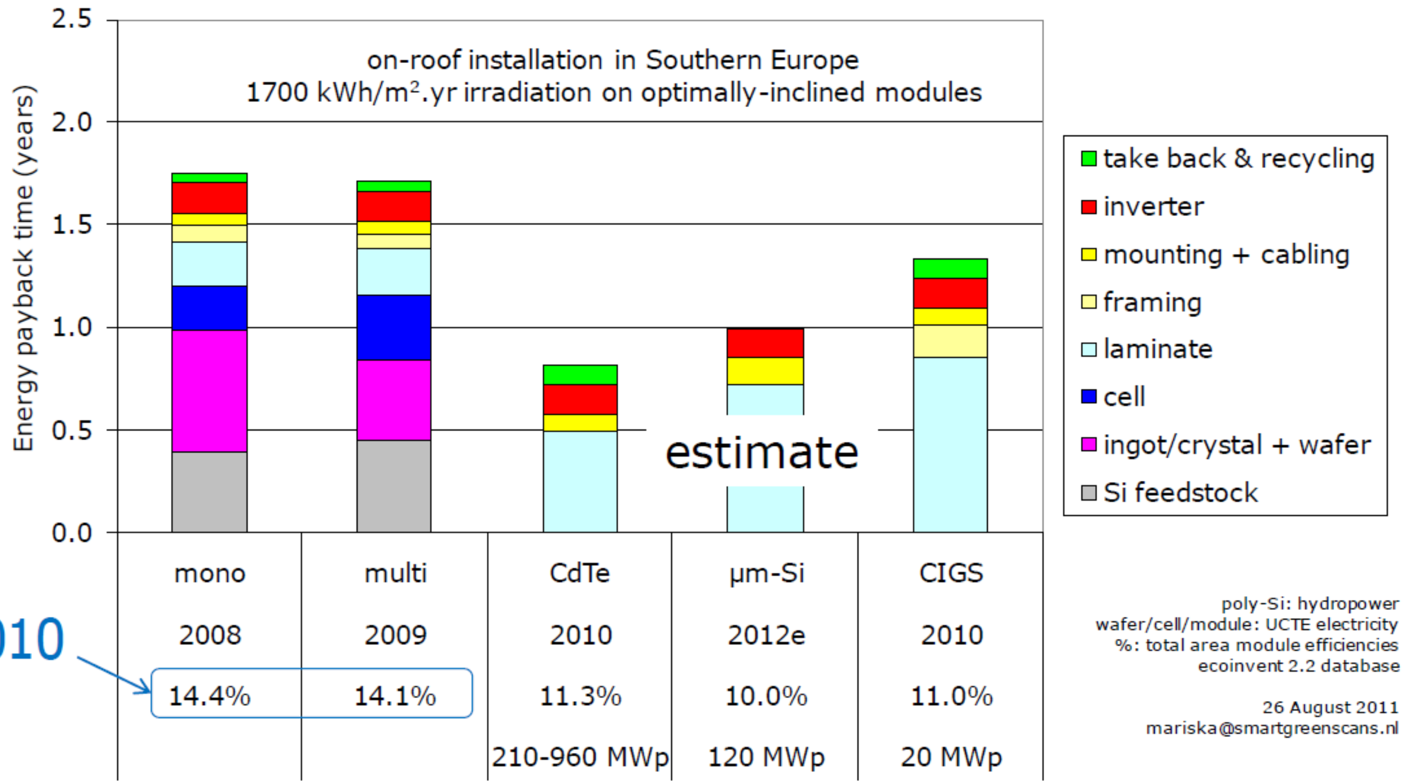
- Supply chain security (and price stability)
- Cradle-to-cradle approach
- Low (zero, or positive) impact:
  - manufacturing
  - installation
  - operation
  - decommissioning
- Public acceptance

First Solar

# Public acceptance: *not to be taken for granted*


Courtesy Michael Marčák

# Energy payback time



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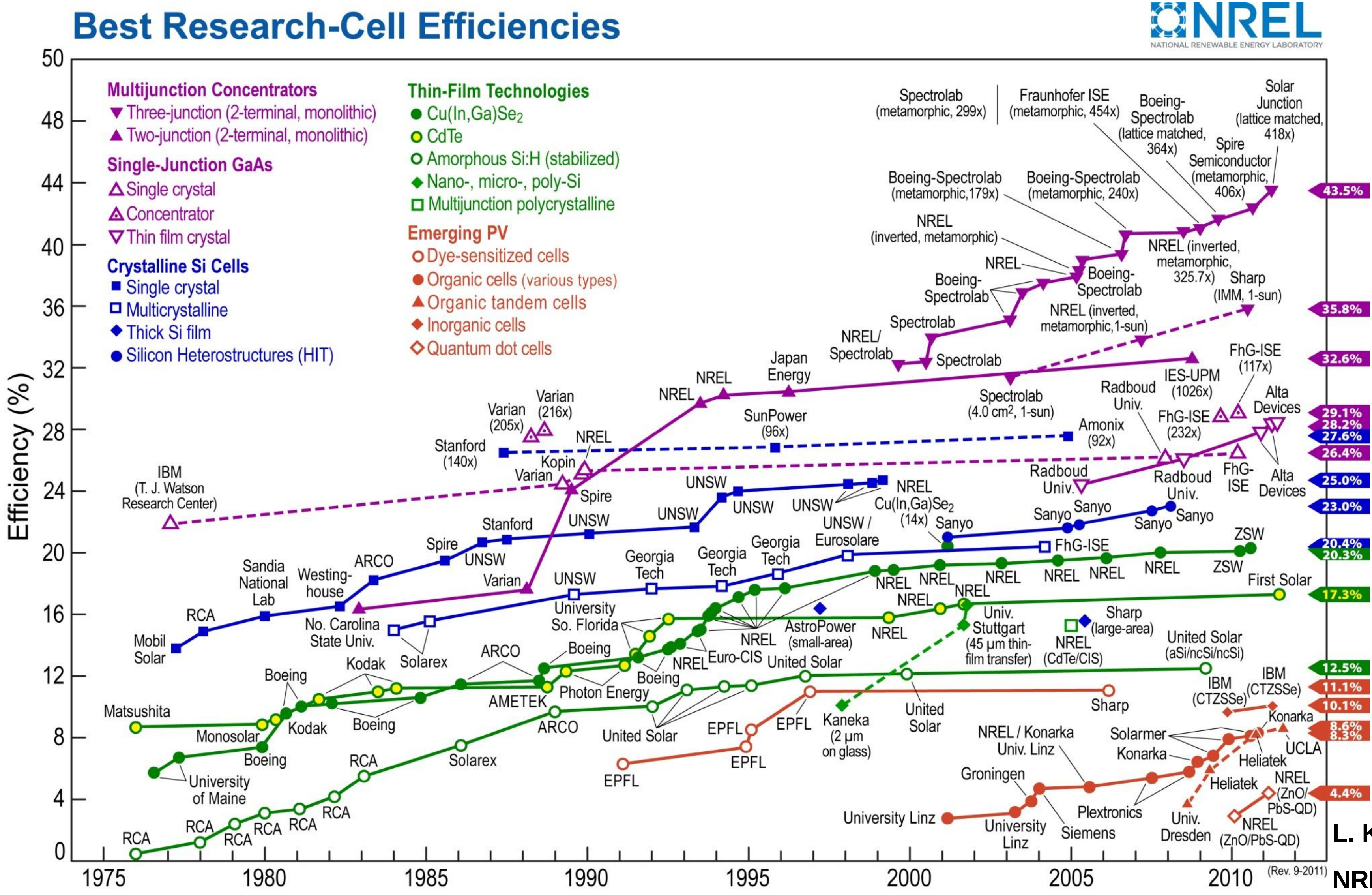
ECN

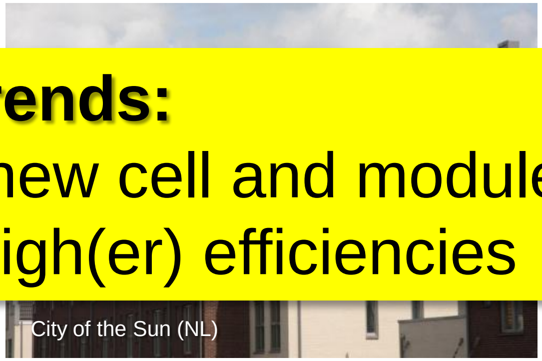
PhotoVoltaic TECHNOLOGY PLATFORM




L. Kazmerski

NREL, 2011

# Cell & module technologies

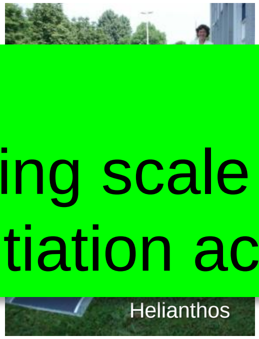


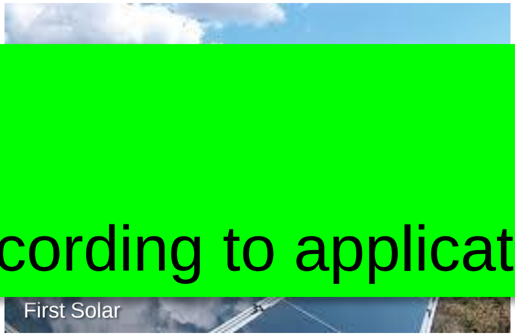


**Trends:**
- new cell and module architectures
- high(er) efficiencies

**Commercial (flat plate):**
**wafer-based silicon**
- monocrystalline
- multicrystalline

*Module efficiencies 14 ~ 20%*


**Trends:**
- increasing scale
- differentiation according to application

**Commercial (flat plate):**
**films**
on
per-indium/gallium-diselenide (CIGS)
mium telluride (CdTe)

*Module efficiencies 7 ~ 13%*

**Trends:**
- commercial applications taking off
- (even) smaller gap lab/fab efficiencies

**ncentrator):**
**I-V semiconductors**

*ies 25 ~ 30%*

# Cell & module technologies

**Trends:**

- applications of nanotechnology
- synergy with other fields of technology

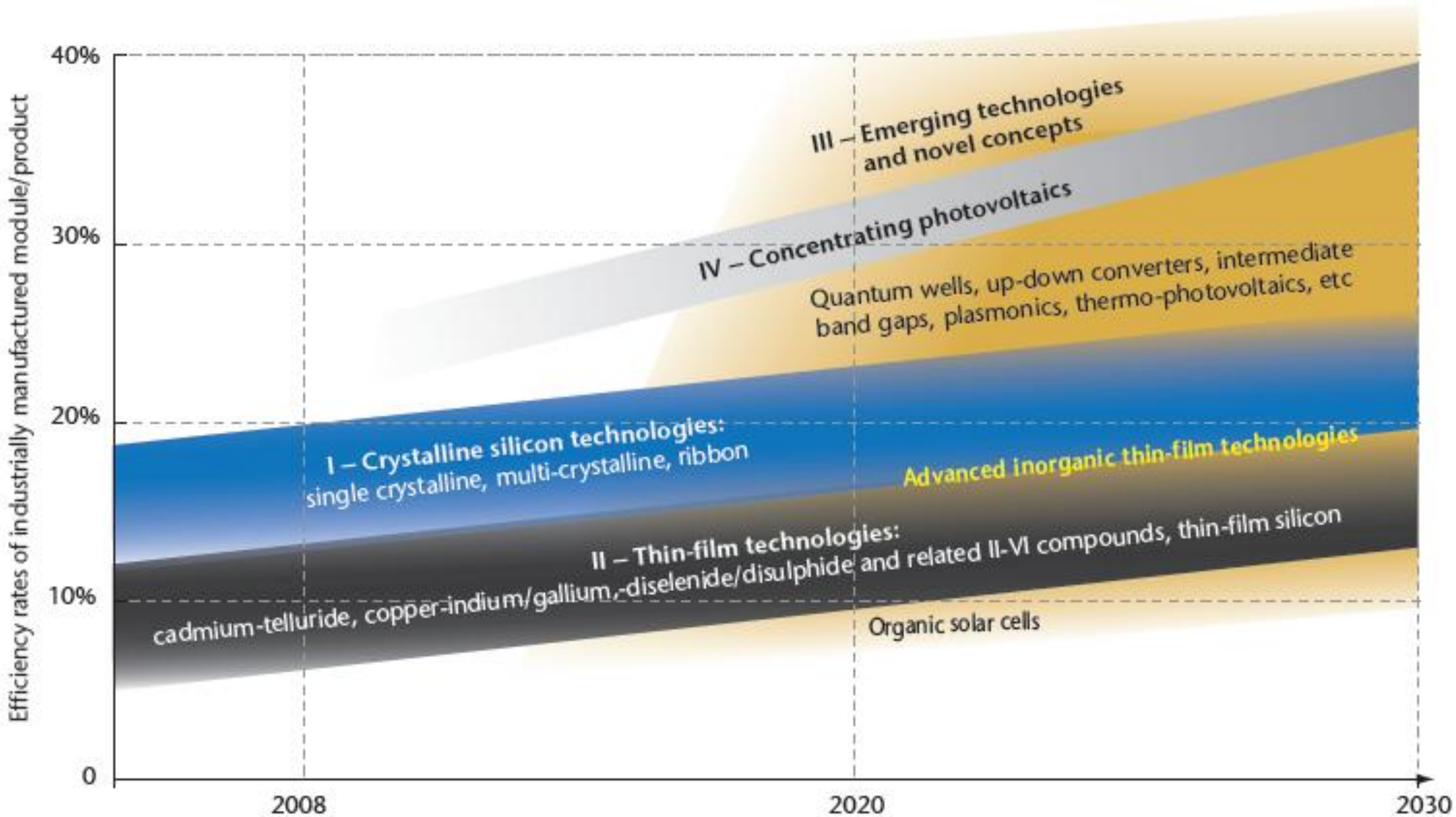
**g and novel technologies:**

-cost concepts

ogies for new applications)

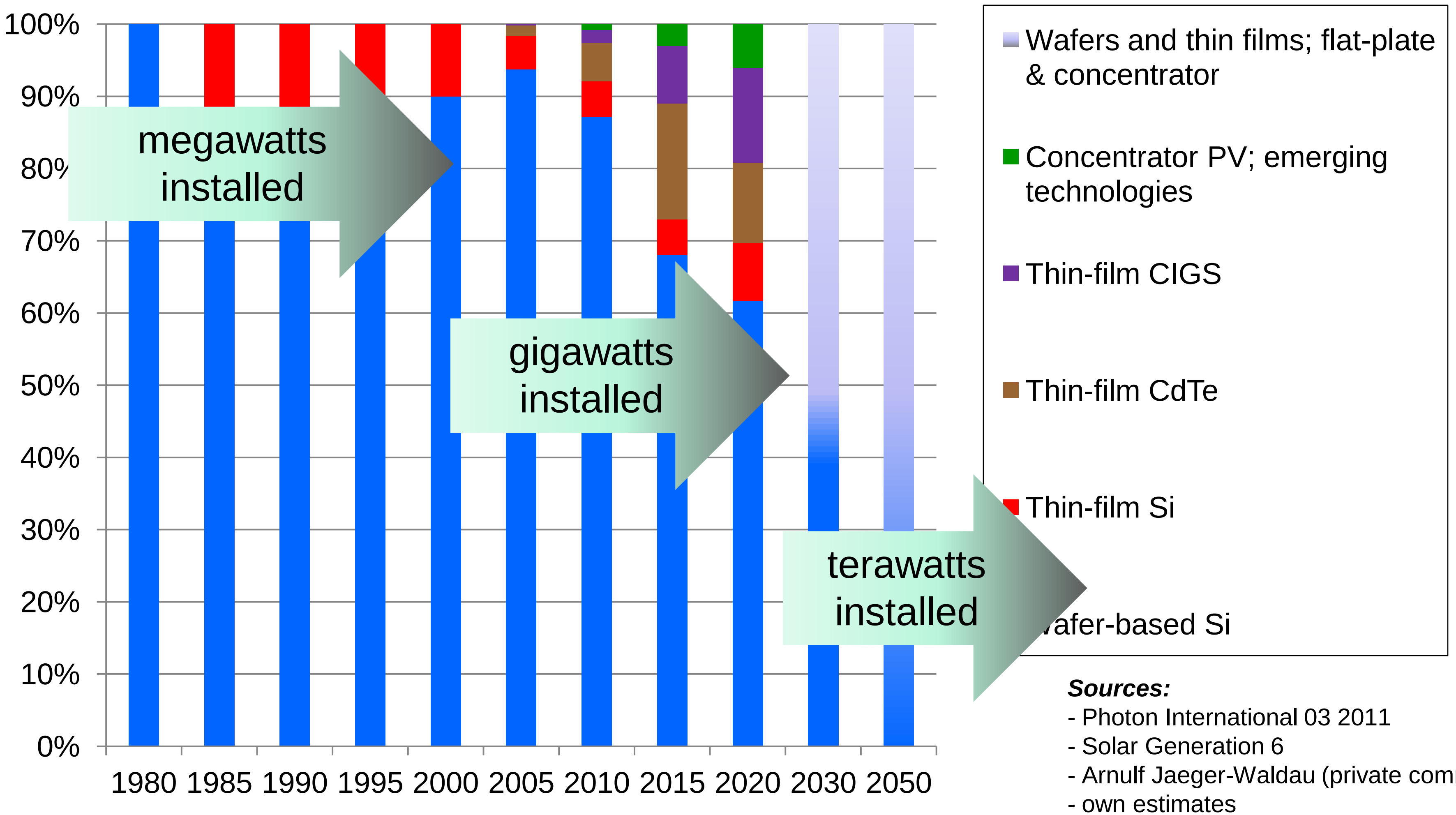
h-efficiency concepts

# Evolution of technology portfolio and module efficiencies *(IEA PV Roadmap, 2010)*




*Source*: IEA PVPS.

# PV technology shares




***Sources:***
- Photon International 03 2011
- Solar Generation 6
- Arnulf Jaeger-Waldau (private comm.)
- own estimates

# System approaches

- (k)Wp to GWp
- stand-alone, grid-connected, minigrid
- BAPV, BIPV, ground based, and more
- single-purpose or multifunctional
- PV-only or hybrid (PV-T, PV-wind, etc.)
- fixed orientation, one & two-axis tracking
- modular or central design
- *and more*

Sharp Corp.

Mun. Heerhugowaard

Enel

Phoenix Solar

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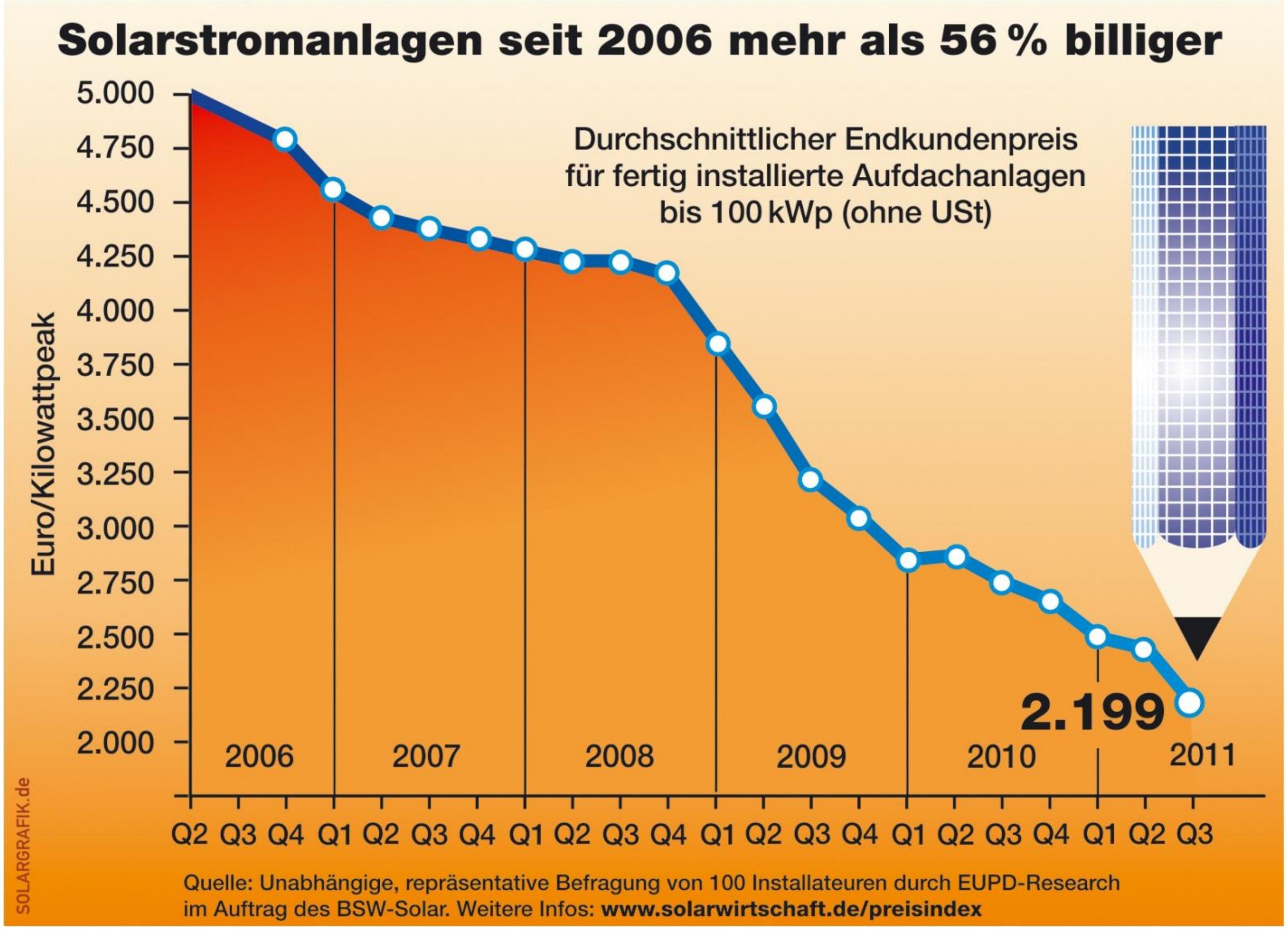
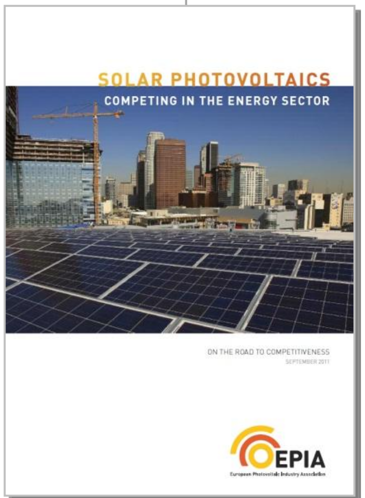
# PV system price development – German rooftops
## (BSW-Solar, 2011)



# Price evolution solar modules (Europe)



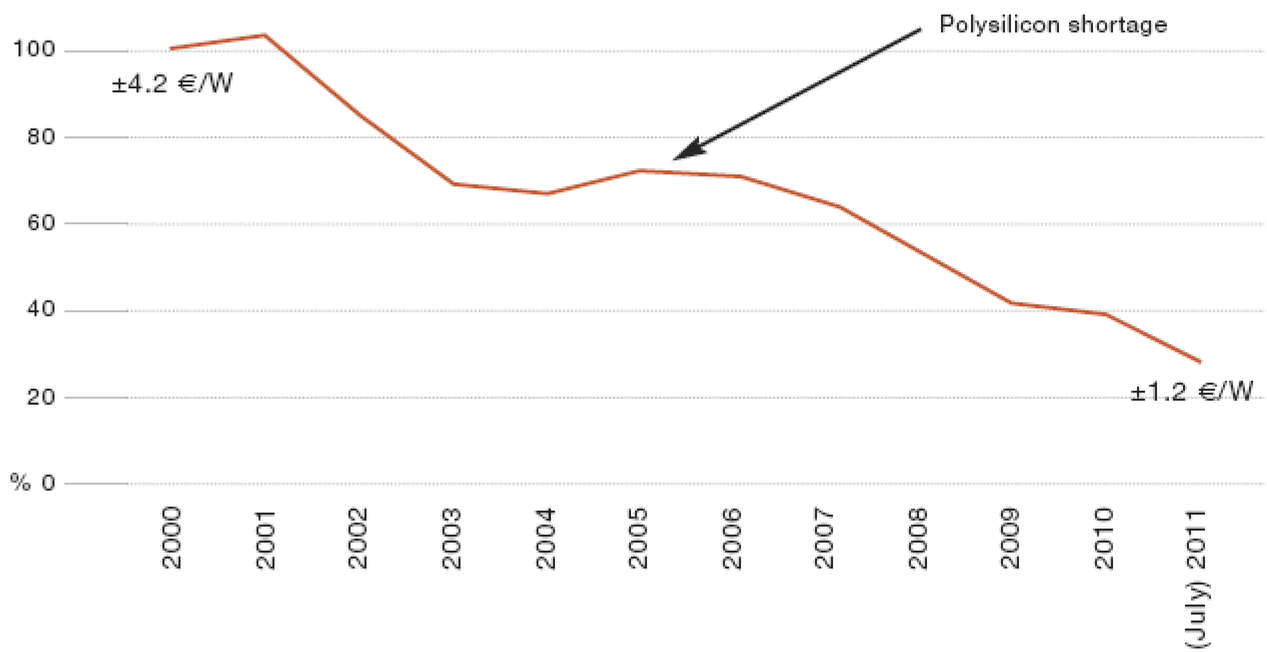
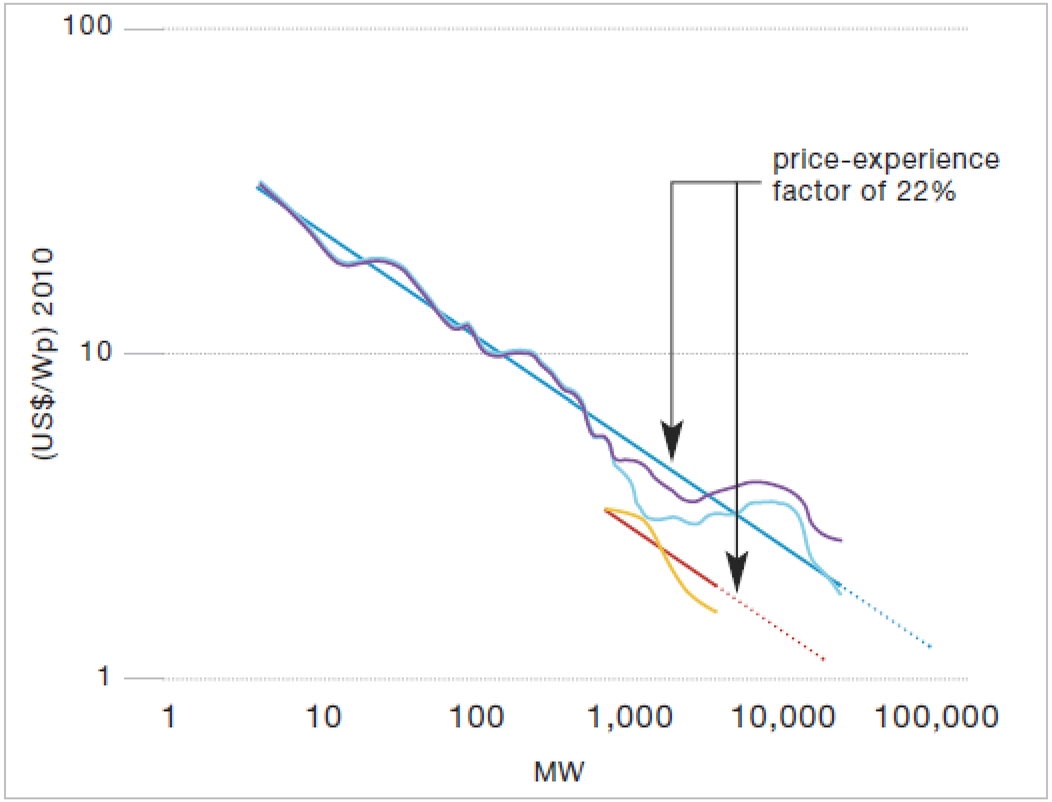



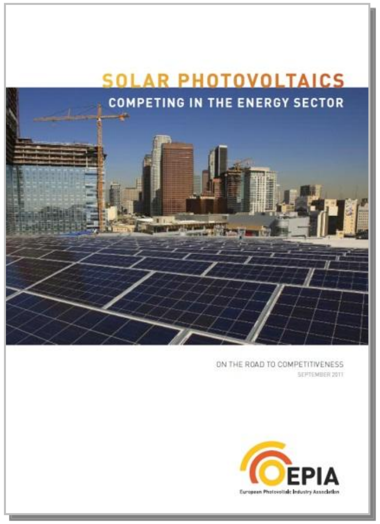

Figure 3 - Evolution of the average PV module price in Europe

**source:** Price data based on Paula Mints (Navigant Consulting).

# Price-experience curves solar modules

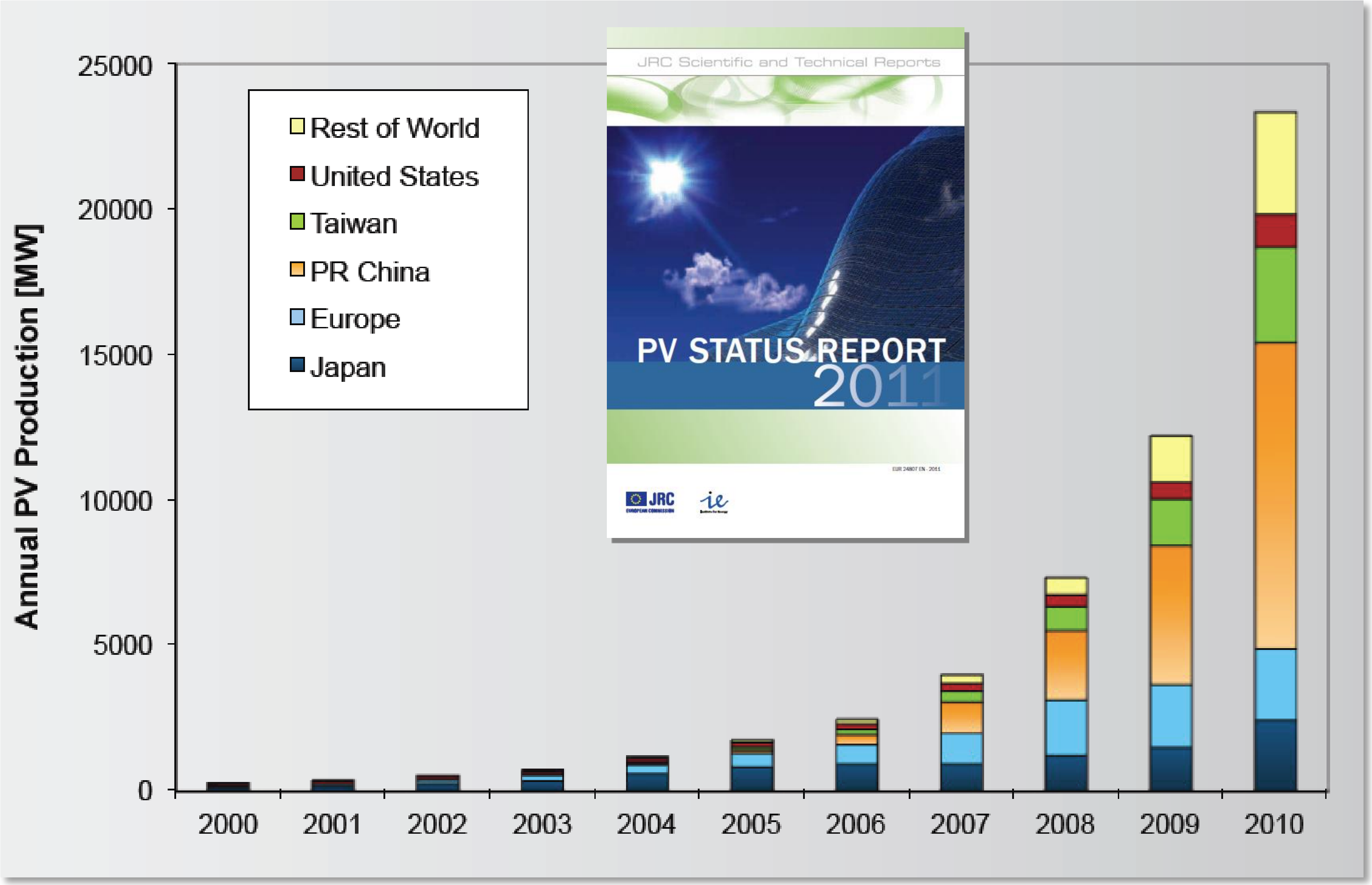
## *the combined effect of volume and innovation*



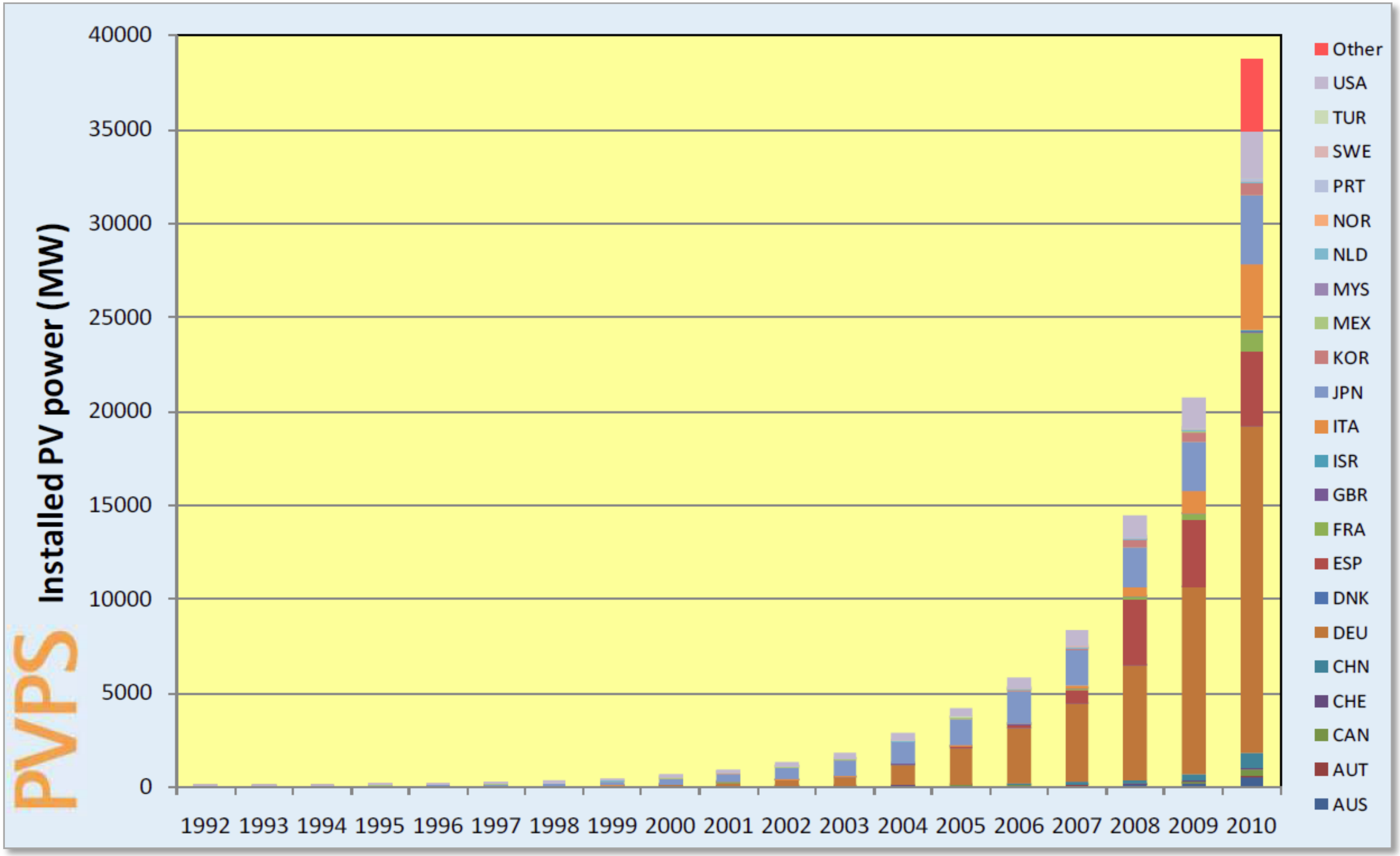




source: Navigant Consulting, EPIA.

# PV cell and module production



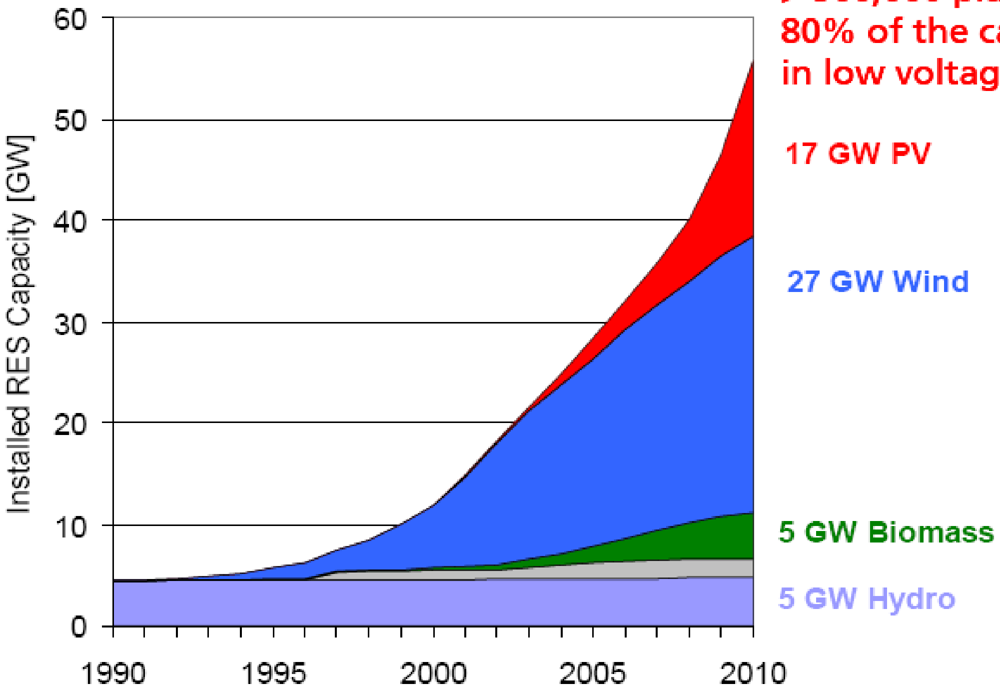
# Cumulative installed capacity (IEA PVPS, 2011)



# Germany leads the way

Increase of Renewable Energy Sources in Germany 1990 - 2010

June 2011:
> 900,000 plants
80% of the capacity
in low voltage grids




Courtesy M. Lippert, SAFT

Data Source: BMU, March 2011

**Martin Braun**
**@ EU PV TP General Assembly**
**(Brussels, 2011)**

Prof. Dr.-Ing. Martin Braun
„The Development of Smart Grids - High Penetration of PV into the Grid"
6th General Assembly of the European Photovoltaic Technology Platform
30 June 2011 – European Parliament, Brussels, Belgium

4

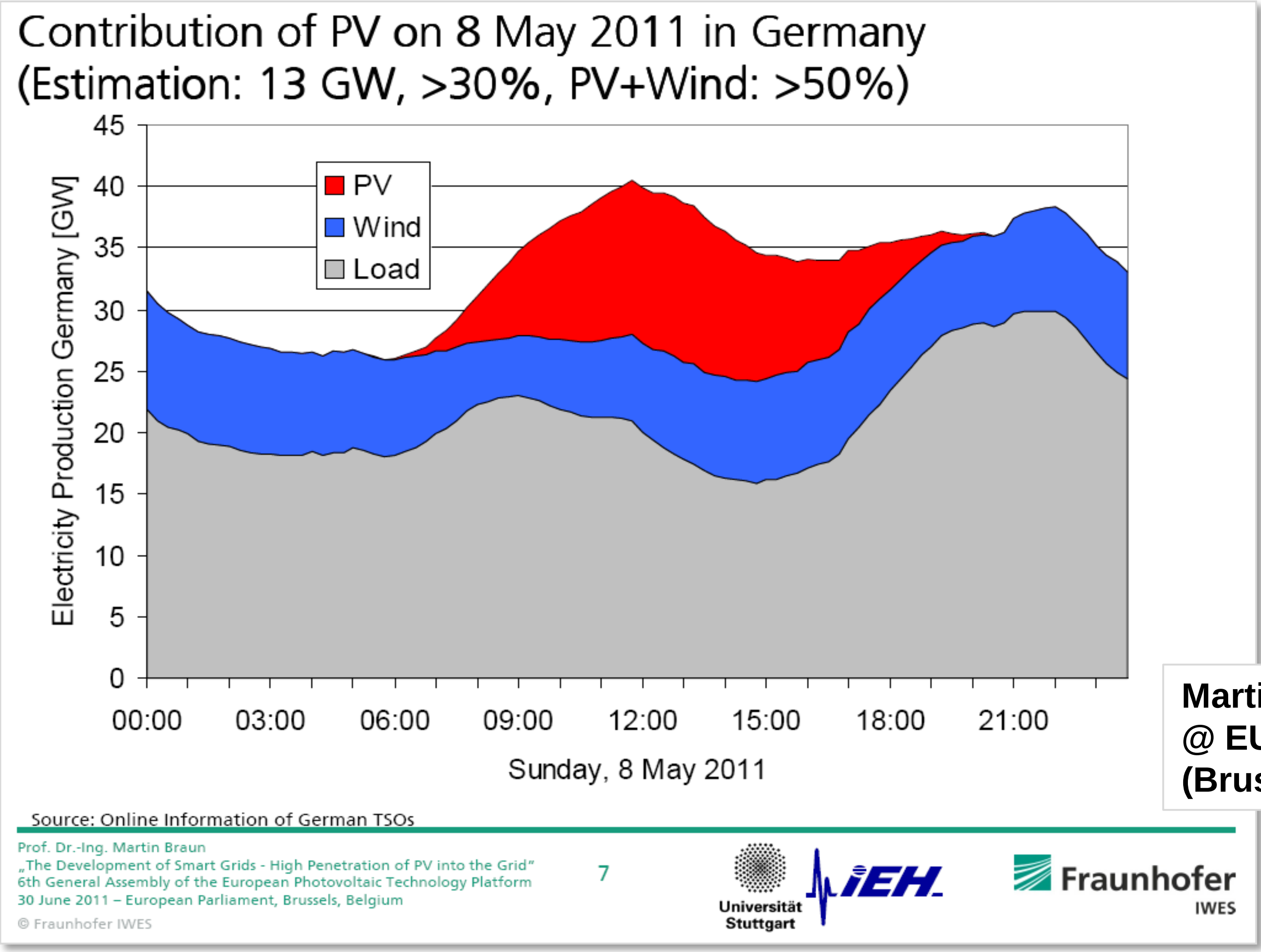


Universität Stuttgart

iEH

Fraunhofer IWES

# PV is far beyond a niche already

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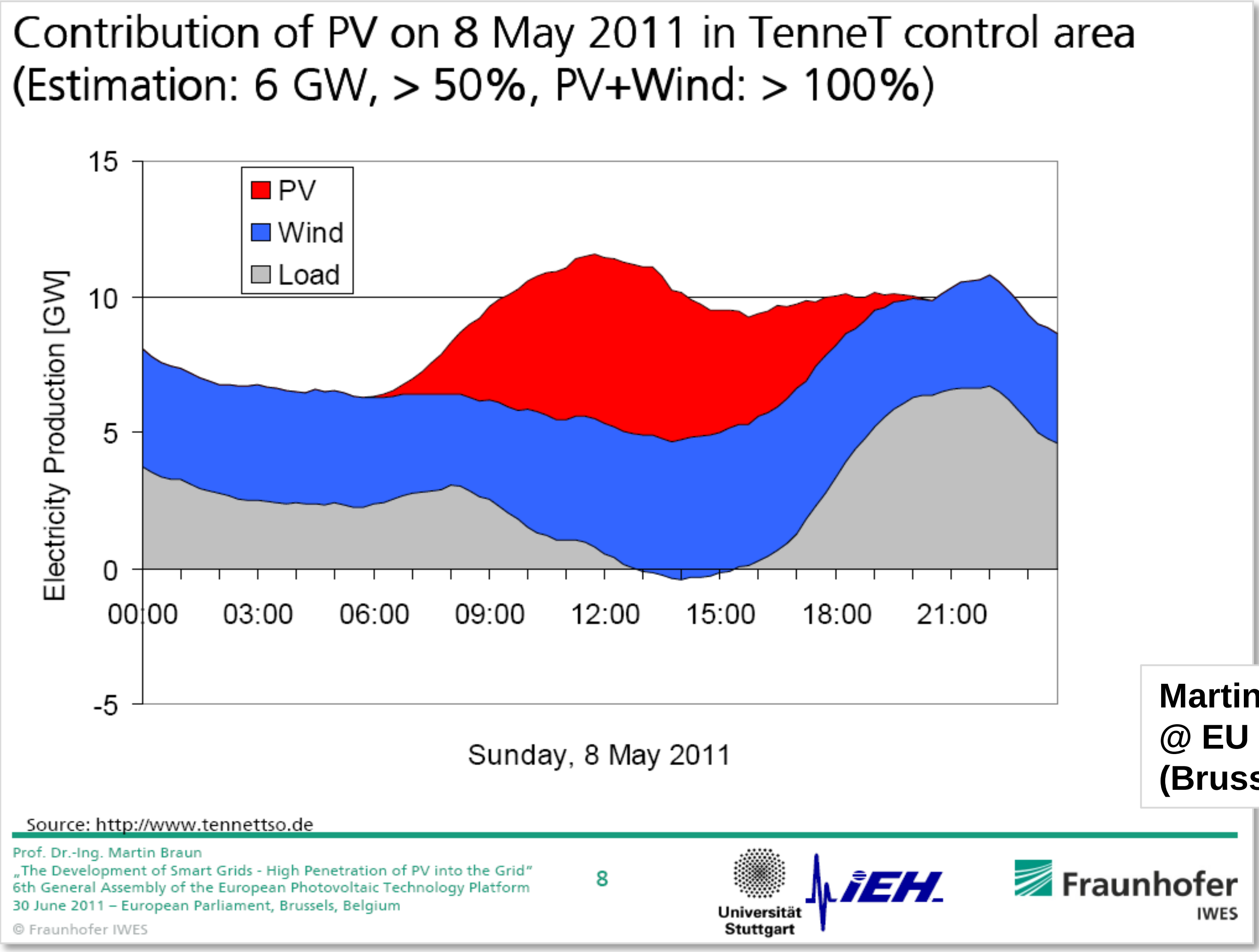
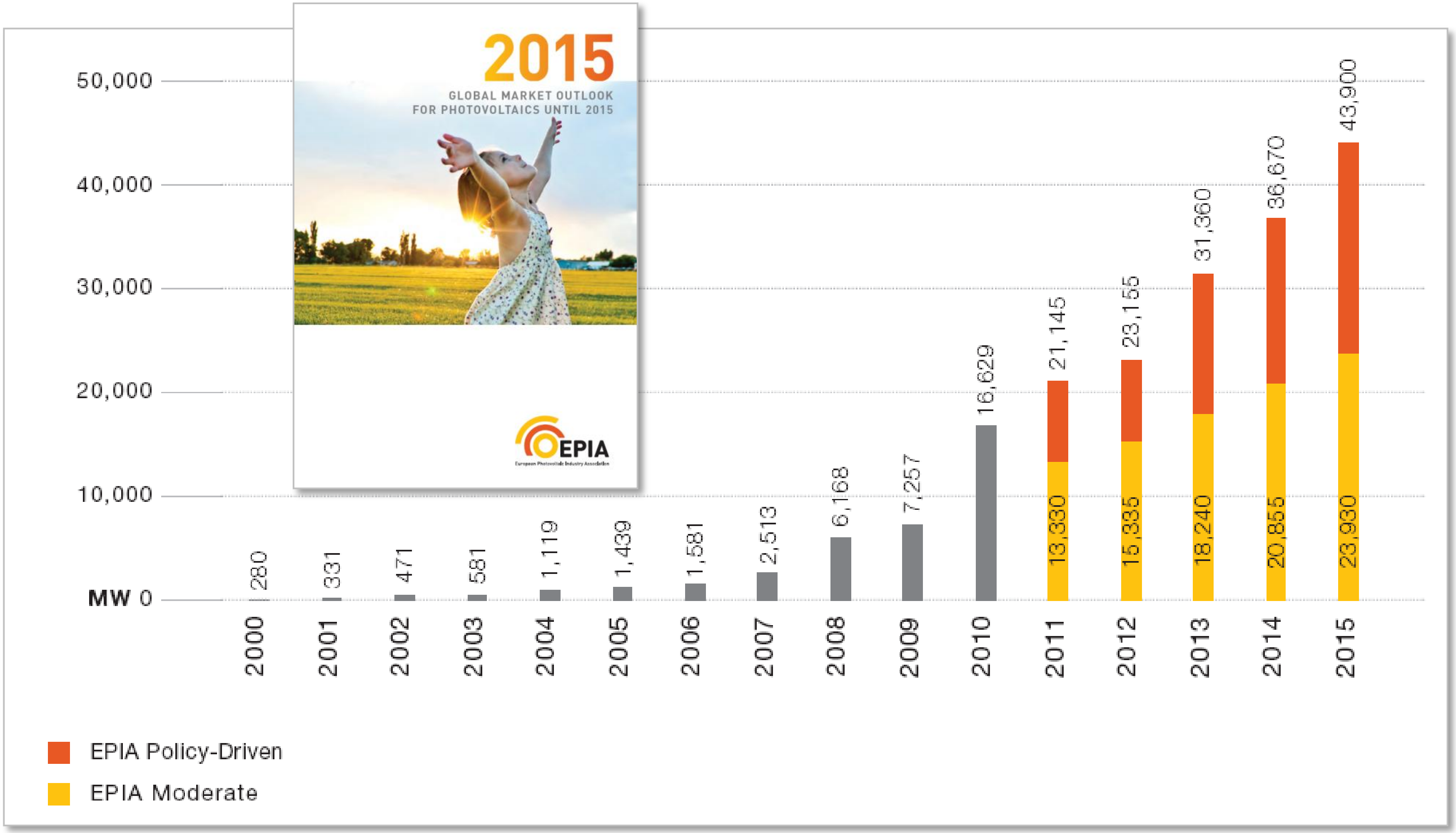



**Martin Braun**
**@ EU PV TP General Assembly**
**(Brussels, 2011)**

# Projected annual installed capacity (EPIA, May 2011)

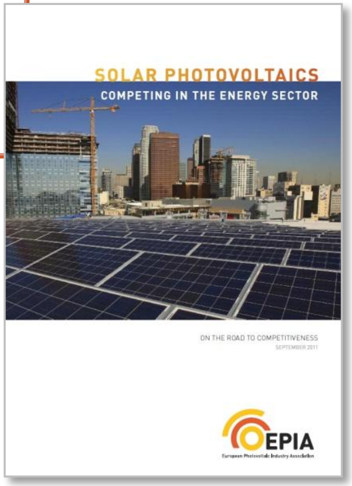


# A competitive solution well before 2020

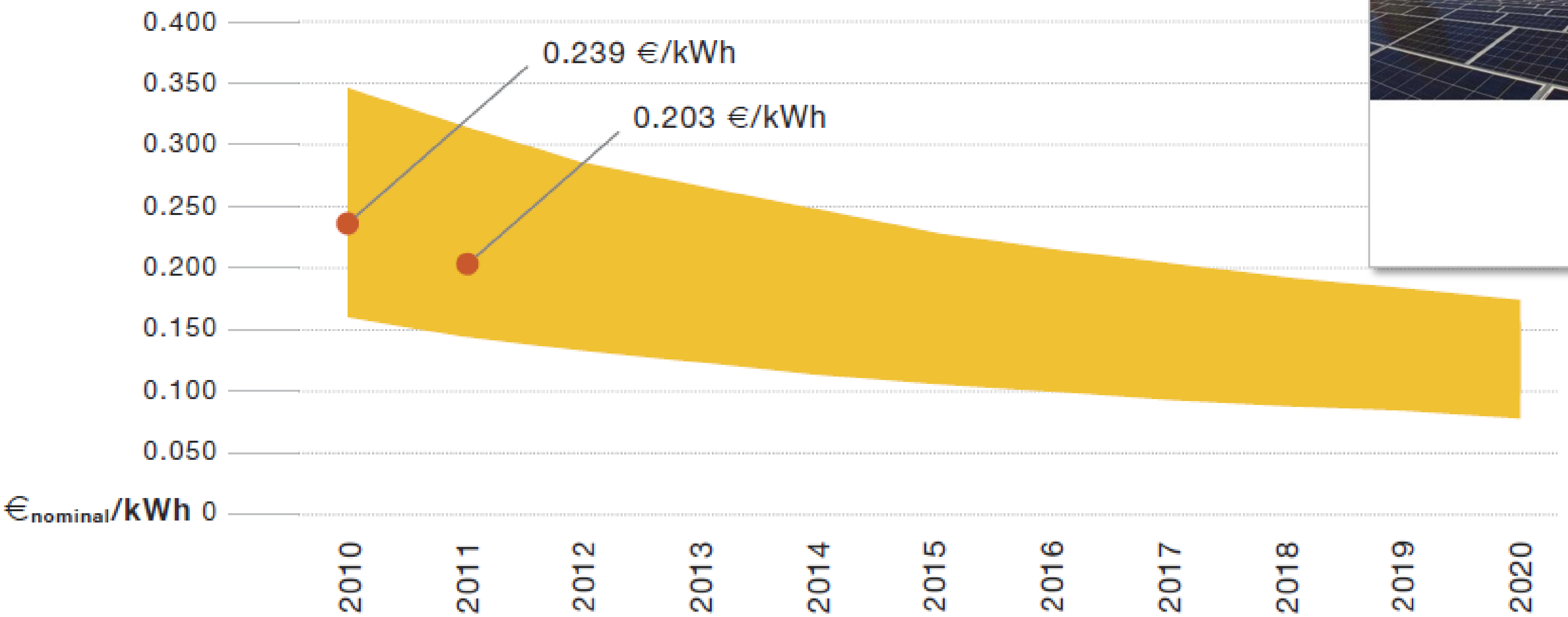
Competitiveness is analysed by comparing PV's generation cost with the PV revenues (dynamic grid parity) and/or with the generation cost of other electricity sources (generation value competitiveness).

**"Dynamic grid parity"** is defined as the moment at which, in a particular market segment in a specific country, the present value of the long-term revenues (earnings and savings) of the electricity supply from a PV installation is equal to the long-term cost of receiving traditionally produced and supplied power over the grid.

**"Generation value competitiveness"** is defined as the moment at which, in a specific country, adding PV to the generation portfolio becomes equally attractive from an investor's point of view to investing in a traditional and normally fossil-fuel based technology.



# Projected development of generation costs
(Levelized Cost of Electricity; LCoE)



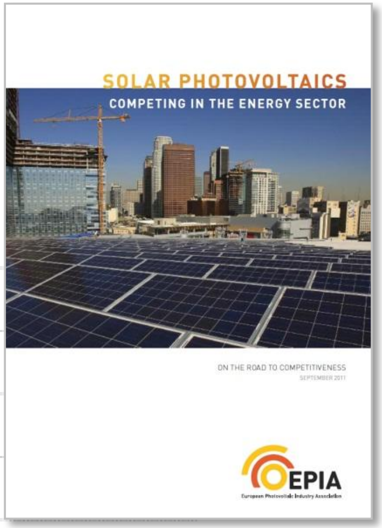




Figure 7 - European PV LCOE range projection 2010-2020

# Competitive position solar electricity (“dynamic grid parity”): *residential systems*

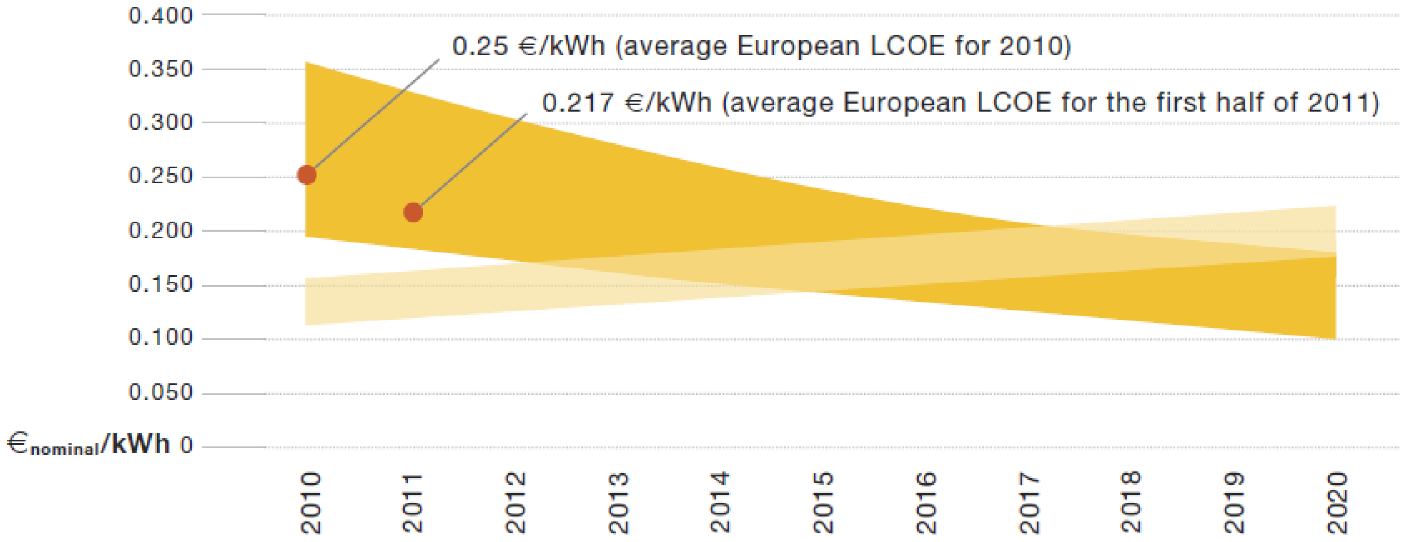
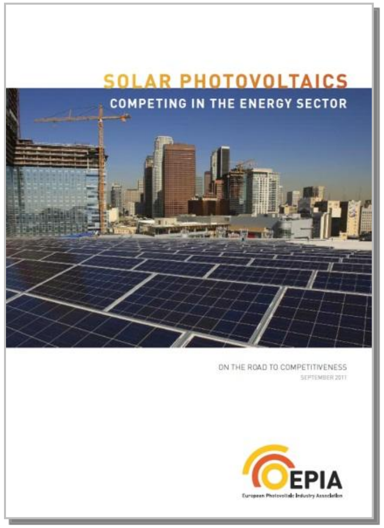



Figure 12A - Dynamic grid parity for residential PV systems in Europe



# Competitive position solar electricity ("dynamic grid parity"): *power plants (CCGT)*

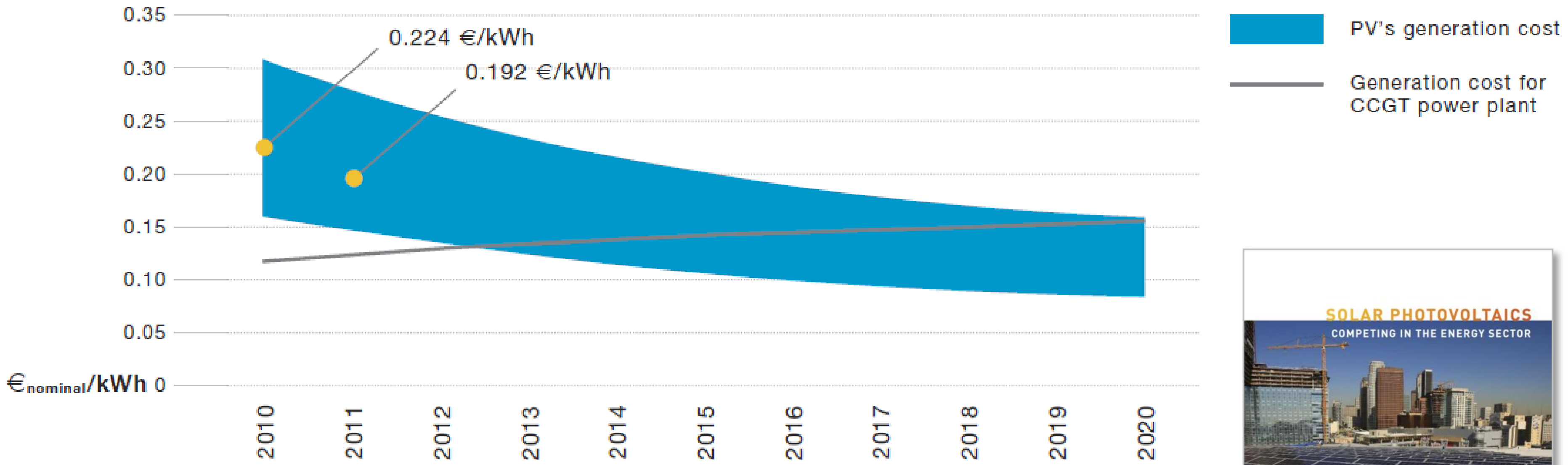
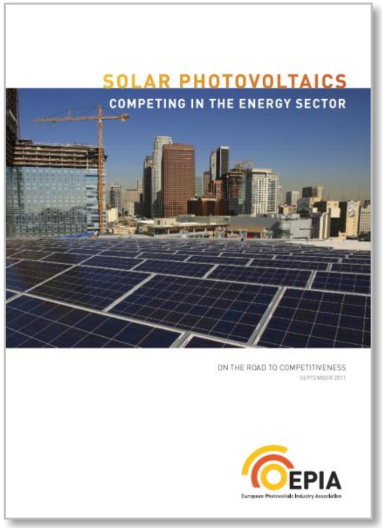


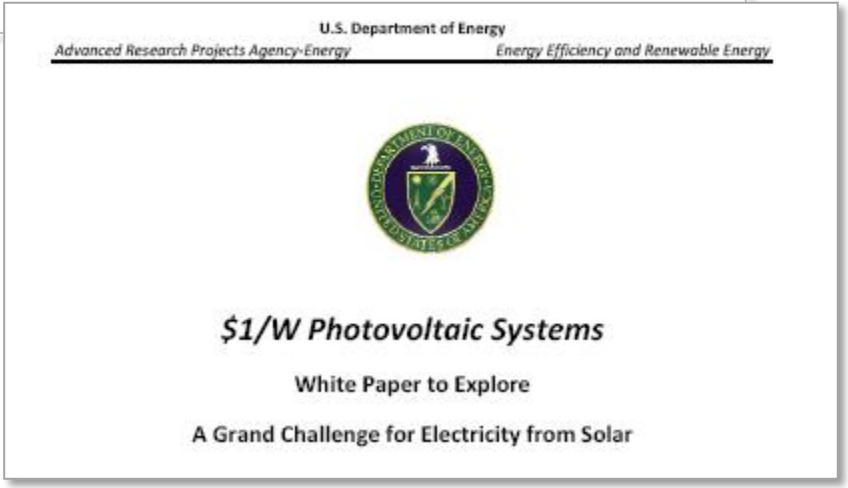

Figure 12D - Generation value competitiveness of large ground-mounted applications in Europe (comparison with CCGT power plant)



# USA DoE SunShot Initiative

## *Cost-competitive utility-scale PV by 2020*

*At a total installed system cost of utility solar equivalent to the wholesale cost of electricity from fossil fuels — approximately $0.05–$0.06 per kilowatt-hour (kWh) — PV would be broadly competitive across the United States without any subsidies. At $0.05–$0.06 per kWh, the system cost is approximately $1 per watt.*


U.S. Department of Energy
Advanced Research Projects Agency-Energy
Energy Efficiency and Renewable Energy

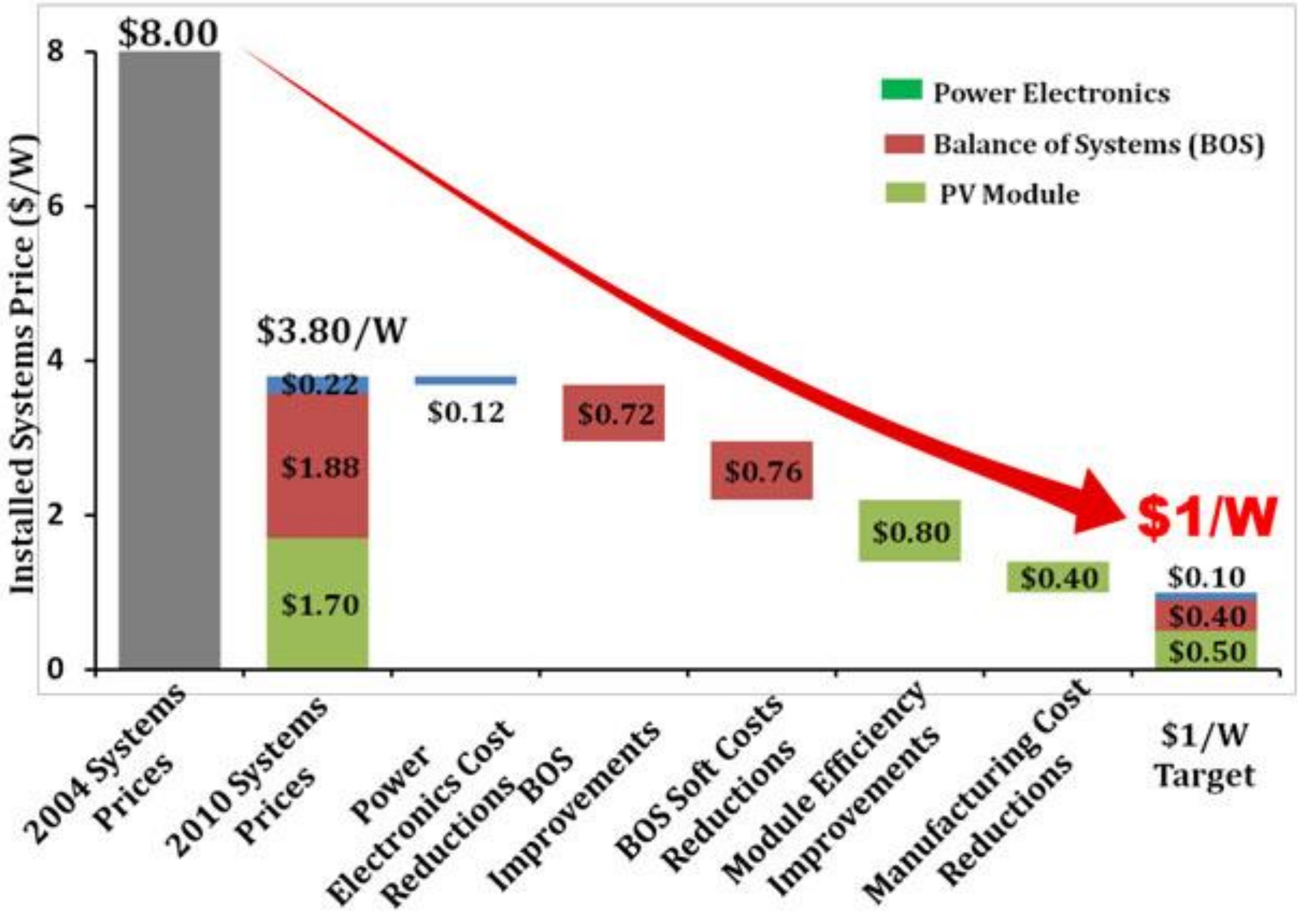
$1/W Photovoltaic Systems

White Paper to Explore

A Grand Challenge for Electricity from Solar

## USA DoE SunShot Initiative

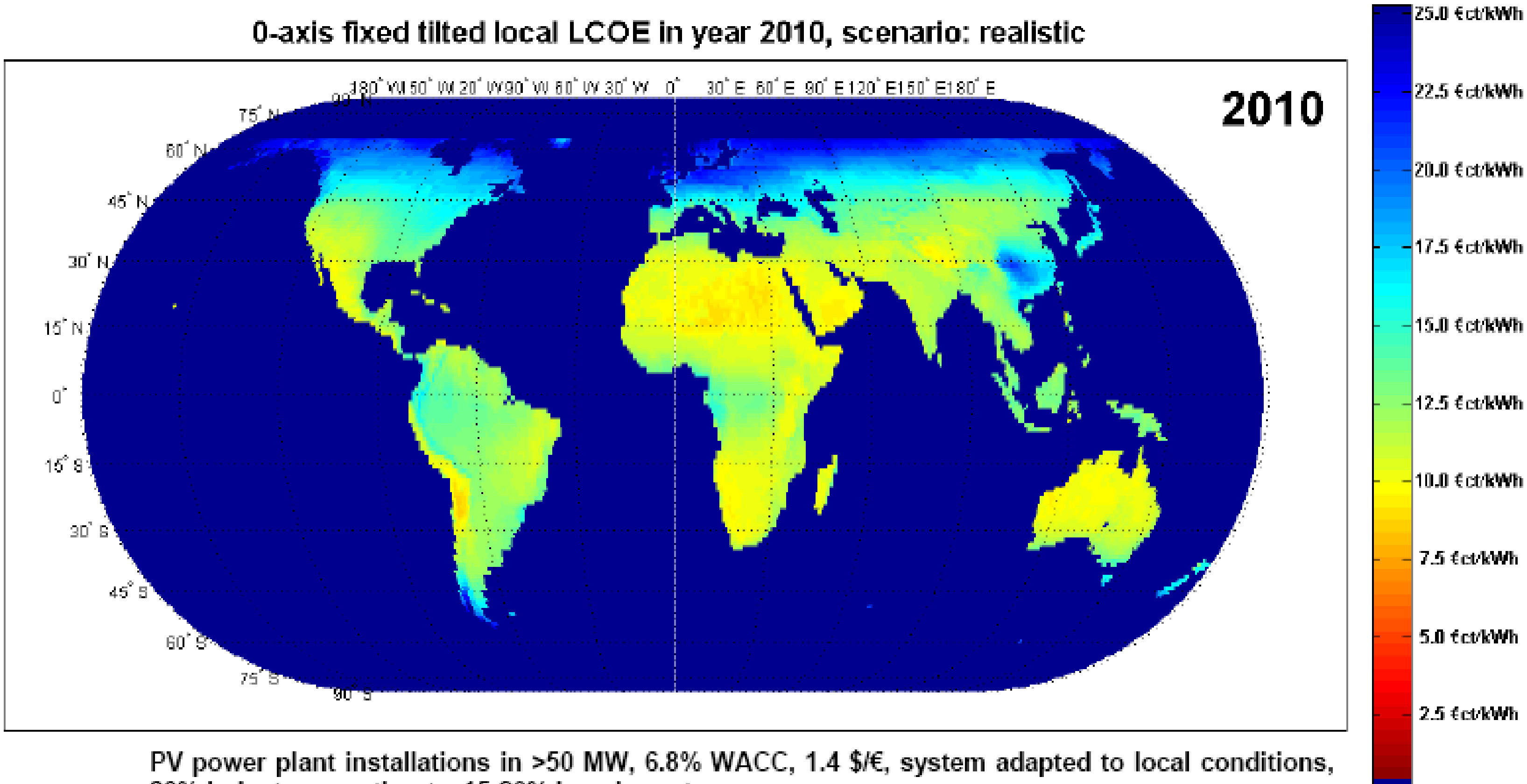
***Cost-competitive utility-scale PV by 2020***



# PV Cost Dynamics

Christian Breyer
@ EUPVSEC26
(Hamburg, 2011)

0-axis fixed tilted local LCOE in year 2010, scenario: realistic




PV power plant installations in >50 MW, 6.8% WACC, 1.4 $/€, system adapted to local conditions, 30% industry growth rate, 15-20% learning rate

source: Breyer Ch. et al., 2010. Fuel-Parity: New Very Large and Sustainable Market Segments for PV Systems, IEEE EnergyCon, Manama, December 18–22

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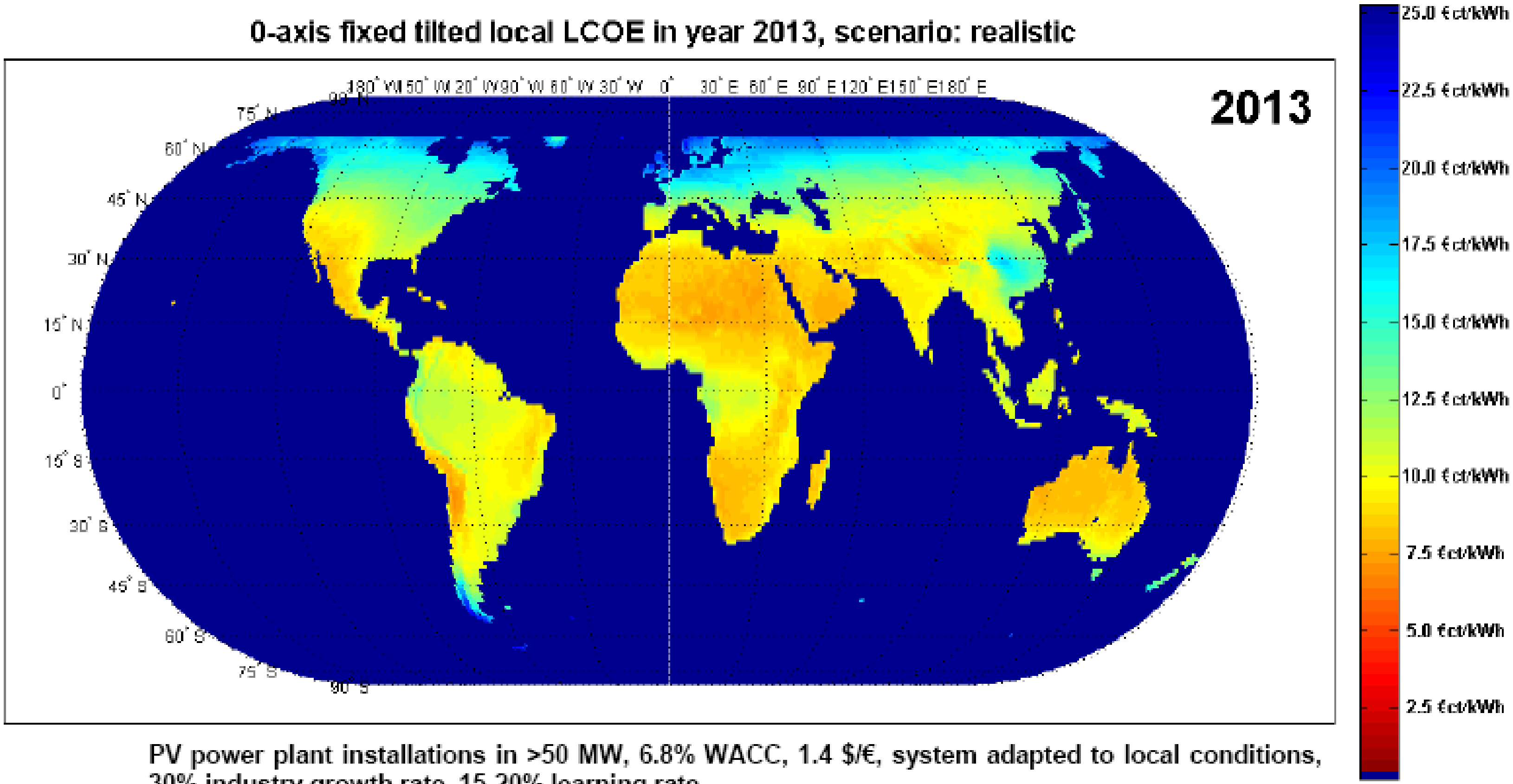


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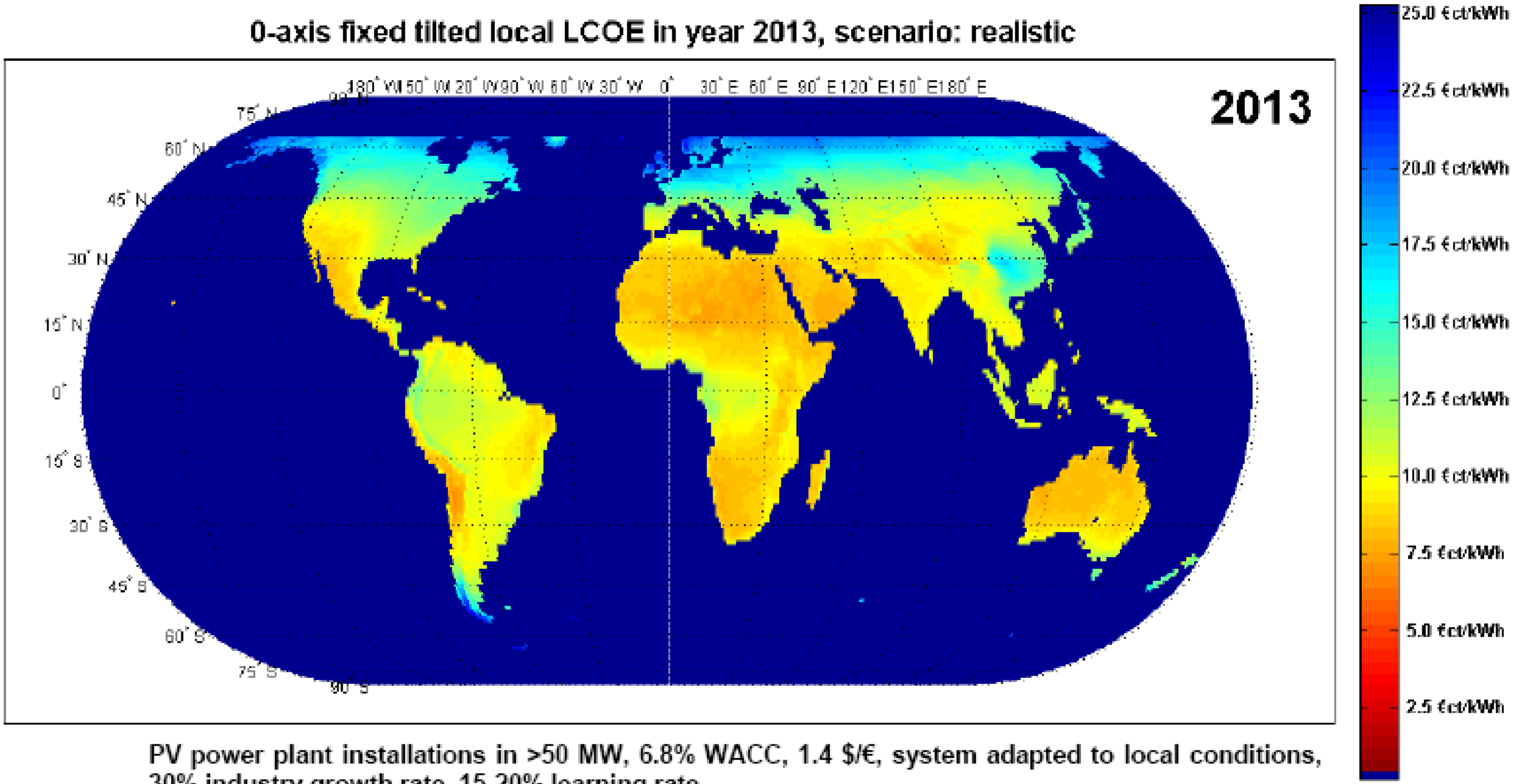


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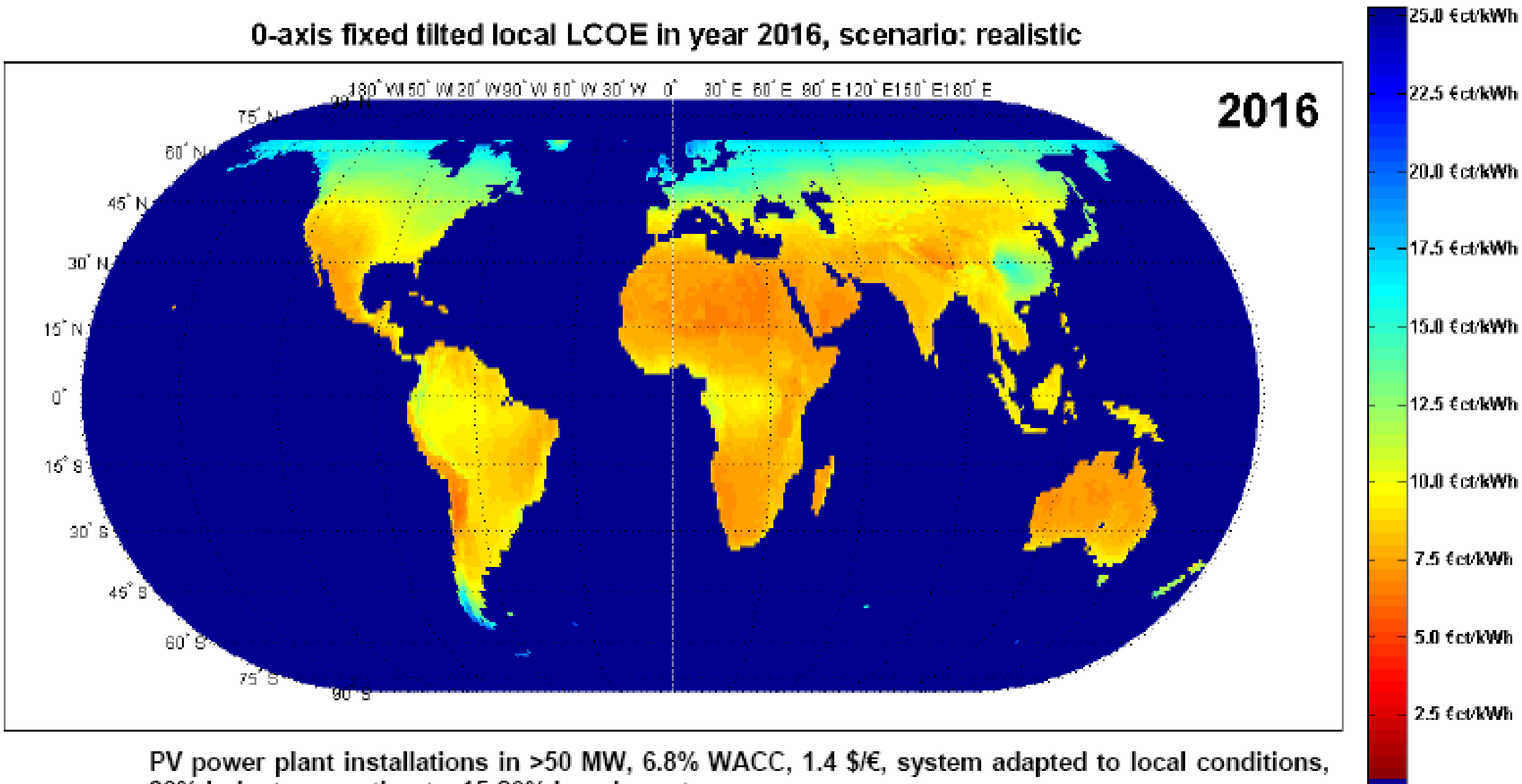


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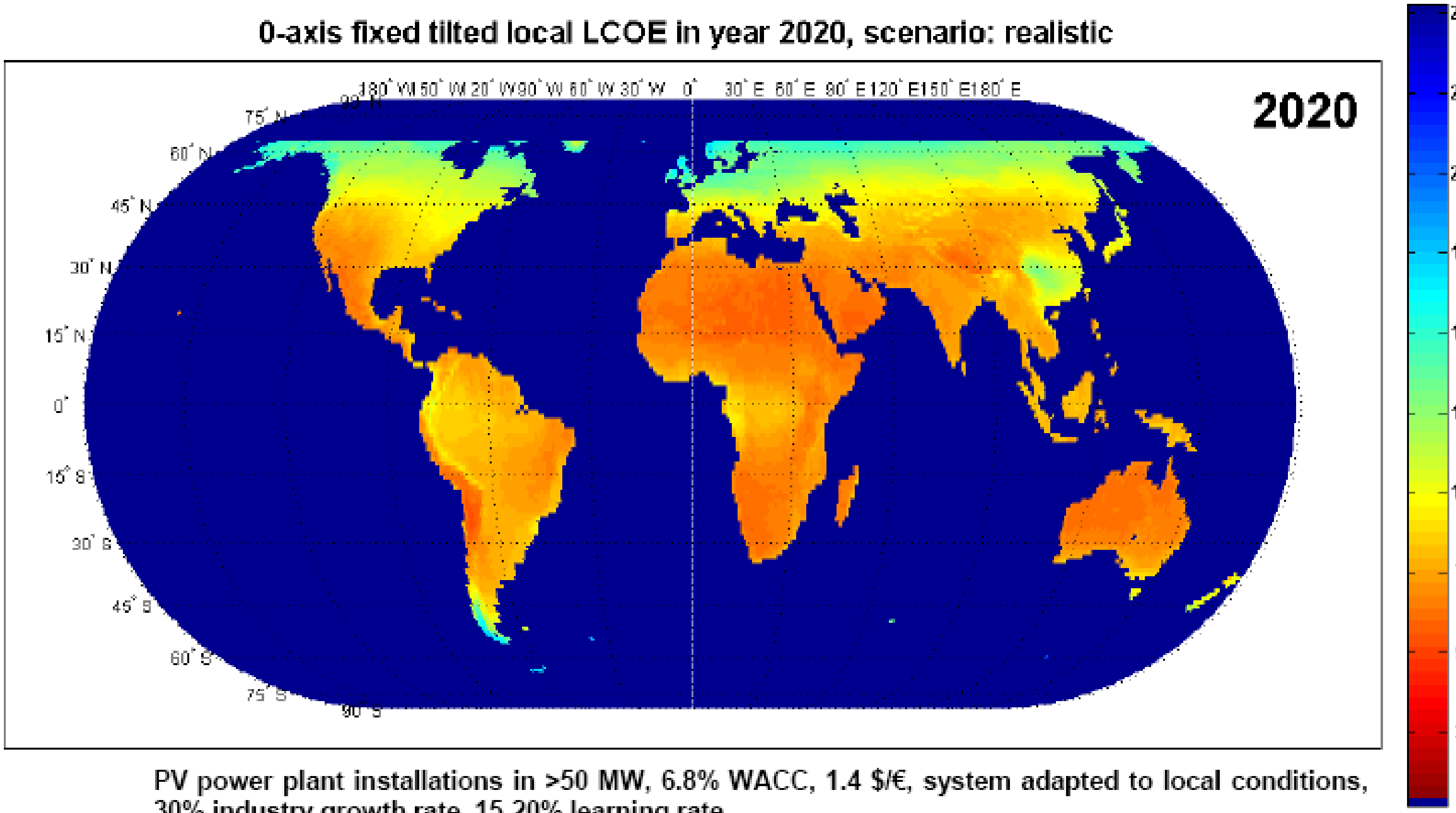


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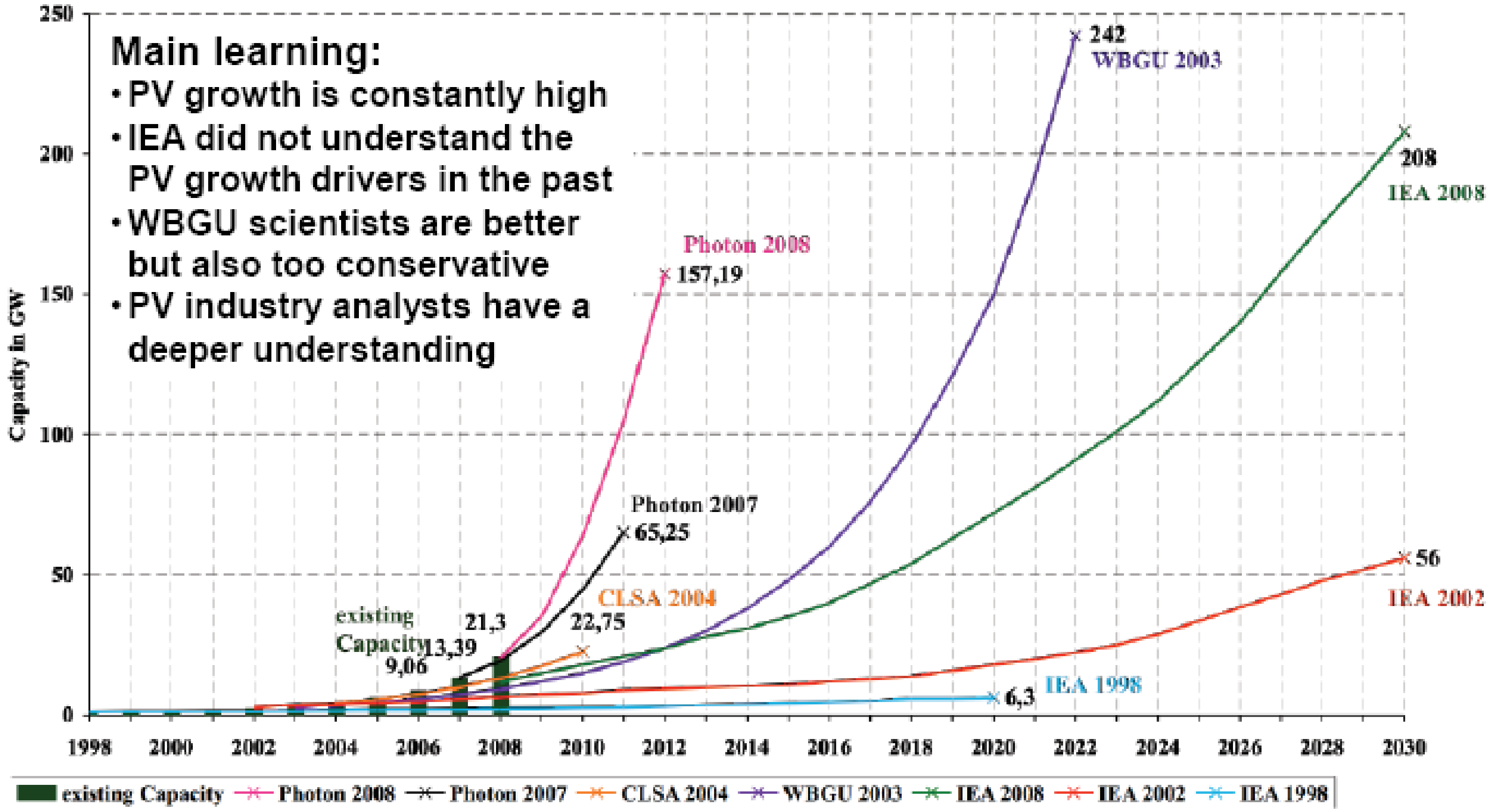
# PV Scenarios in the Past

Christian Breyer @ EUPVSEC26 (Hamburg, 2011)




source: Gredler C., 2008. Das Wachstumspotenzial der Photovoltaik und der Windkraft – divergierende Wahrnehmungen zentraler Akteure, Diploma thesis, University Salzburg

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# Conclusions

Christian Breyer
@ EUPVSEC26
(Hamburg, 2011)

- ongoing fast PV cost reduction is very likely
- PV is still negligible in terms of currently cumulative installed capacities
- Grid-parity start right now (driven by end-user electricity prices)
- Fuel-parity start right now (driven by solar resource quality)
- high (economic) demand for adapted off-grid PV solutions
- economic PV market potential by 2020 roughly 2,800 – 4,300 GWp
- cumulative installed capacity by 2020 roughly 600 – 1,600 GWp
- most institutions cannot imagine a fast PV diffusion (except EPIA, Greenpeace)

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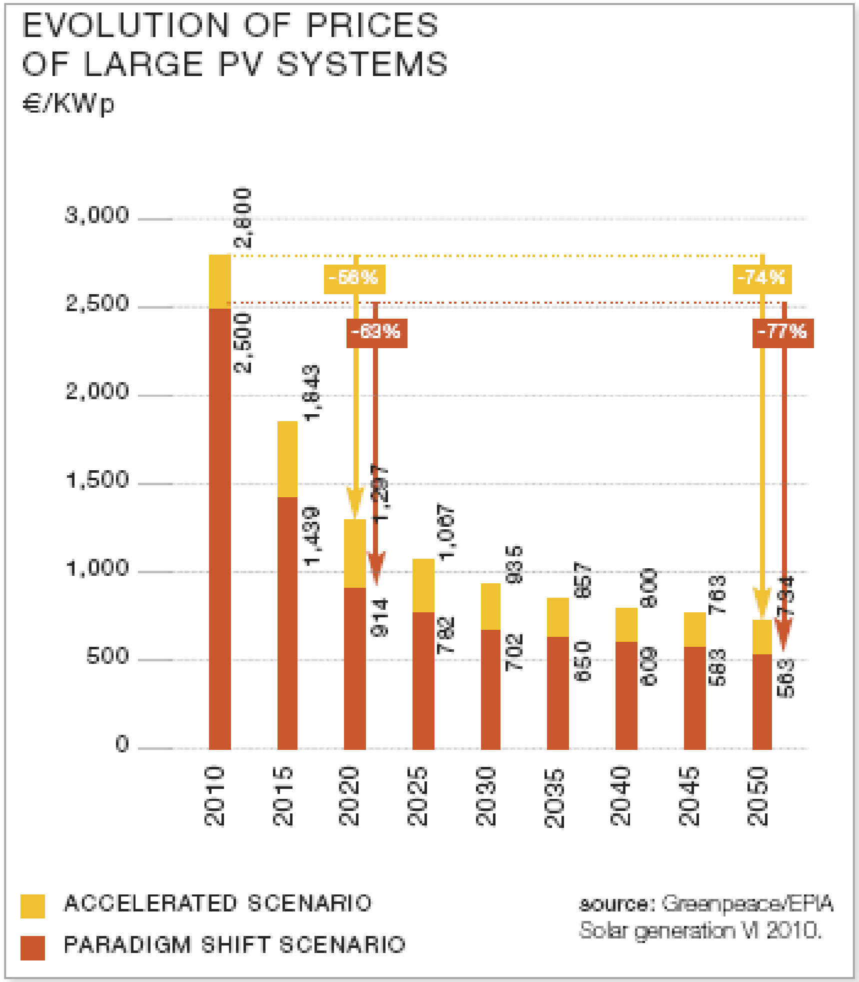
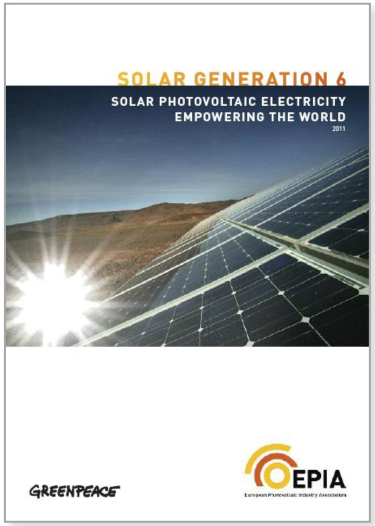
# Solar Generation 6

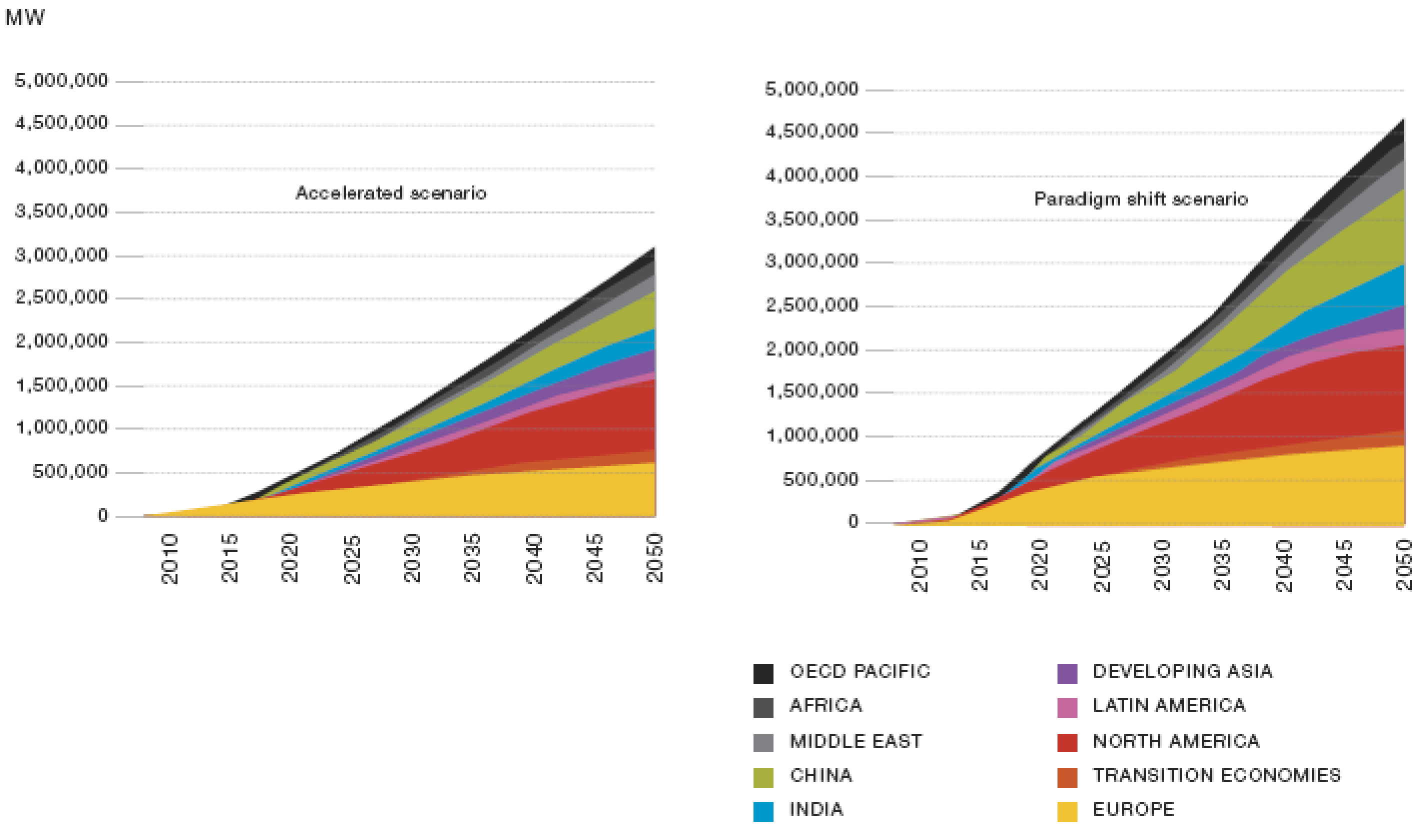
## *Long-term price development utility-scale systems*



# Solar Generation 6

## *Long-term market growth scenarios*




source: Greenpeace/EPIA Solar Generation VI, 2010.

## Table 1: BLUE Map Electricity Capacity (GW) for Selected Technologies Worldwide

| | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|
| Coal w CCS | | | 4 | 22 | 85 | 191 | 341 | 476 | 558 | 663 |
| Natural gas w CCS | | | 1 | 5 | 12 | 37 | 98 | 163 | 224 | 298 |
| **Solar PV** | **8** | **19** | **53** | **126** | **233** | **384** | **630** | **877** | **1132** | **1378** |
| Solar CSP | 1 | 2 | 8 | 42 | 70 | 107 | 187 | 287 | 382 | 473 |
| Wind | 96 | 159 | 322 | 575 | 799 | 1067 | 1315 | 1521 | 1645 | 1732 |

Actual/projected 38 350~1600
130~200 3000~5000 and up

Source: ETP2010, IEA analysis

## Table 2: BLUE Map Electricity Generation (TWh) for Selected Technologies Worldwide

| | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|
| Coal w CCS | 0 | 0 | 29 | 164 | 653 | 1447 | 2578 | 3566 | 4117 | 4746 |
| Natural gas w CCS | 0 | 0 | 2 | 28 | 64 | 207 | 570 | 955 | 1337 | 1815 |
| Biomass w CCS | 0 | 0 | 0 | 0 | 6 | 33 | 83 | 167 | 265 | 311 |
| Biomass | 259 | 304 | 379 | 469 | 855 | 1448 | 1709 | 2025 | 2079 | 2149 |
| **Solar PV** | **4** | **17** | **63** | **144** | **306** | **525** | **1050** | **1514** | **1981** | **2469** |
| Solar CSP | 1 | 3 | 22 | 131 | 235 | 395 | 765 | 1287 | 1849 | 2489 |
| Wind | 173 | 326 | 755 | 1323 | 2045 | 2779 | 3682 | 4190 | 4617 | 4916 |

Source: ETP2010, IEA analysis

**Table 3: BLUE Map Cost Assumptions for Generation Technologies**

| | Investment costs (USD2008/kW) | | | Annual Improvement to | | Assumed Learning Rates |
|---|---|---|---|---|---|---|
| *Year* | *2010* | *2020* | *2050* | *2020* | *2050* | |
| Coal supercritical (SC) | 2100 | 2000 | 1650 | 0.5% | 0.6% | NA |
| Coal ultra-supercritical (USC) | 2200 | 2100 | 1700 | 0.5% | 0.6% | NA |
| Coal IGCC | 2400 | 2250 | 1850 | 0.6% | 0.6% | NA |
| Natural gas combined cycle (NGCC) | 900 | 850 | 750 | 0.6% | 0.5% | NA |
| USC+post-combustion capture | 3400 | 3300 | 2500 | 0.3% | 0.8% | 6%* |
| USC + oxy-fuelling | 3700 | 3600 | 2700 | 0.3% | 0.8% | 6%* |
| IGCC + pre-combustion | | | | | | |
| **Solar PV** | **3500-5600** | **2200-3500** | **1000-1600** | **4.5-4.6%** | **3.1%** | **18%** |
| Solar CSP | 4500-7000 | 3400-5000 | 1950-3000 | 2.8-3.3% | 2.1% | 10% |
| Wind onshore | 1450-2200 | 1300-1900 | 1200-1600 | 1.1-1.5% | 0.5-0.8% | 7% |
| Wind offshore | 3000-3700 | 2300-3000 | 2100-2600 | 2.1-2.6% | 0.9% | 9% |

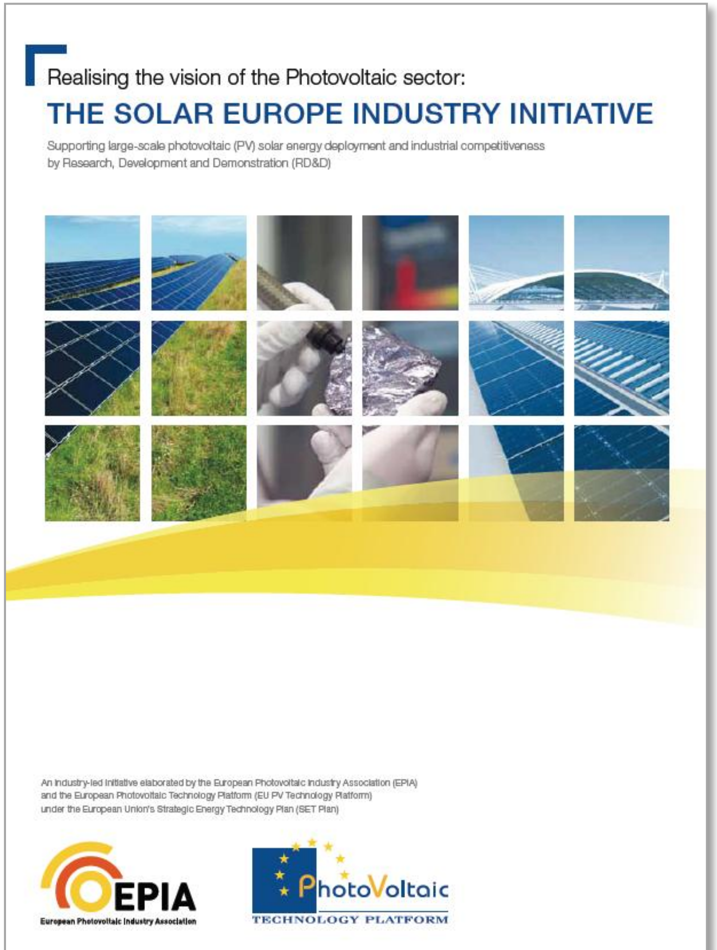
Actual/projected 3000~6000 700~1200*)
1000~2000

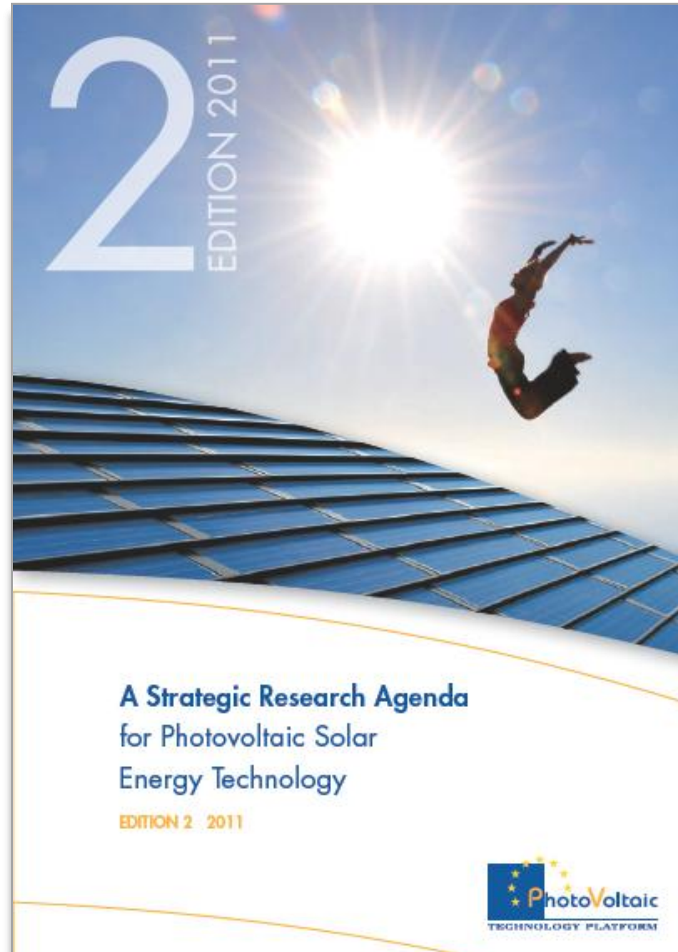
*) Global Energy Assessment (draft, IIASA, 2011)

## Contents



*Background photo: www.bso.vvs.be*


Realising the vision of the Photovoltaic sector:
THE SOLAR EUROPE INDUSTRY INITIATIVE
Supporting large-scale photovoltaic (PV) solar energy deployment and industrial competitiveness by Research, Development and Demonstration (RD&D)
An industry-led initiative elaborated by the European Photovoltaic Industry Association (EPIA) and the European Photovoltaic Technology Platform (EU PV Technology Platform) under the European Union's Strategic Energy Technology Plan (SET Plan)
EPIA
European Photovoltaic Industry Association
PhotoVoltaic
TECHNOLOGY PLATFORM


2
EDITION 2011
A Strategic Research Agenda for Photovoltaic Solar Energy Technology
EDITION 2 2011
PhotoVoltaic
TECHNOLOGY PLATFORM

# Development targets SRA2

| | Today | 2020 | 2030 | Long term potential |
|---|---|---|---|---|
| Typical turn-key price for 100 kWp system (2011 €/Wp, excl. VAT) | 2.5 | 1.5 | 1 | 0.5 |
| Typical electricity generation costs, Southern Europe (2011 €/kWh) | 0.19 | 0.10 | 0.06 | 0.03 |
| Typical system energy payback time, Southern Europe (years) | 0.5-1.5 | <0.5 | <0.5 | 0.25 |

*100 kWp commercial roof system, Italy*
*PR of 80%, yield of 1440 kWh/kWp*
*25 year lifetime, discount rate of 6.5%*
*Current and 2020 values consistent with SEII KPIs*

## General scientific & technological challenges for PV cells & modules (selection)

**High performance (= high efficiency & high annual yield)**

- maximize absorption; minimize recombination losses
- apply efficient concentration *(high X, light trapping)*
- utilize full spectrum *(multi gap, multi band, multi carrier, photon conversion, and more)*

**Low cost**

- high efficiency *(leverage at all levels)*
- low materials cost *(ultra-thin layers, low-cost materials)*
- high-throughput processing *(vacuum & non-vacuum)*

**Sustainability**

- minimum materials & energy use; (design for) recycling
- alternative materials *(CIS → CZTS, Ag → Cu, etc.)*

# General scientific & technological challenges for PV systems (selection)

**High performance (= high efficiency & high annual yield)**

- sun tracking
- high availability (system reliability)
- low electrical losses (DC/AC conversion, cabling, mismatch, etc.)
- (self) cleaning

**Low cost**

- high efficiency
- low materials cost
- fast preparation & installation, low maintenance, replacement & repair

**Sustainability**

- "low BoS" designs, low-energy, abundant materials
- (design for) recycling

# General scientific & technological challenges for system integration (selection)

**High performance**

- electrical integration: avoid having to switch down or off
- physical integration: optimize system lay-out, select optimum sites

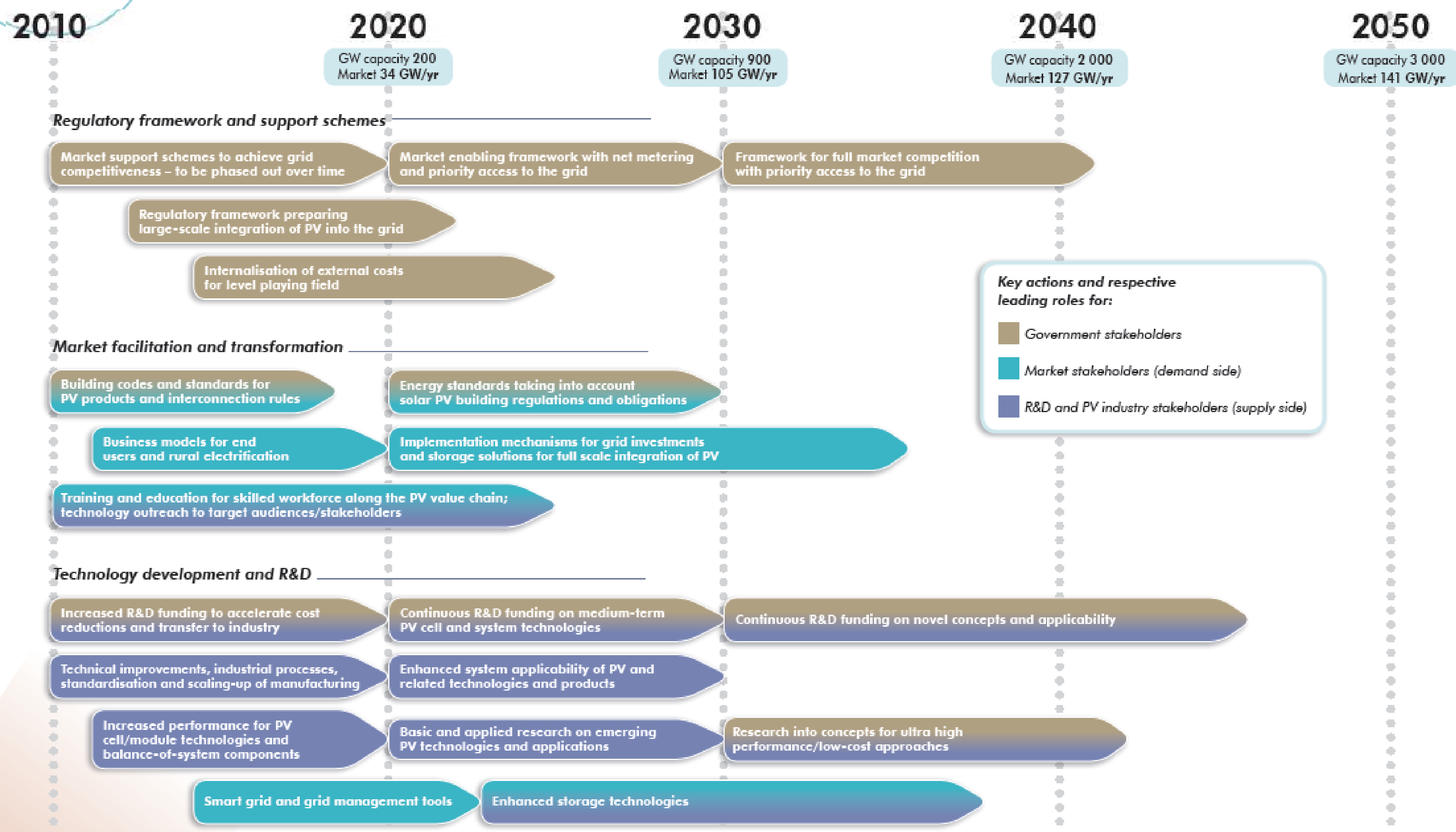
**Low cost**

- electrical integration: concepts & technologies for high penetration *(see e.g. prof. Martin Braun's (FhG-IWES) and dr. Tim Meyer's (DTMC))*
- physical integration: standardisation, prefab, integrated fixtures, click-on/click-off, etc.

**Sustainability**

- electrical integration: optimize energy technology portfolio
- physical integration: low-impact & durable materials (design for) recycling, low intrusion, good aesthetics

## Solar photovoltaic roadmap milestones




International Energy Agency
www.iea.org/roadmaps

## Contents



*Background photo: www.bso.vvs.be*

## From incentive-driven to self-sustained markets

- **Quality first** *(TW-scale use requires professional quality, not just bottom-low prices: “Trust comes by foot and leaves by horse”)*
- **Develop bridging business (& system) concepts**
- **Careful communication** *(grid parity on consumer level in a few countries is not enough to kick-start self-sustained global markets)*

# From technology push to market pull

- **Leading companies build up large in-house R&D capacity**

- **Industry sets the agenda in major R&D programs**

- **Role of public research shifts:**

  *from multi-parter joint development projects to more emphasis on:*

    - *open innovation models*
    - *bilateral competitive R&D*
    - *developing high-risk high-potential options (beyond industry scope)*

## Contents

**The PV challenges quantified**

**Building blocks for the solution**

- technology portfolio & system approaches

**Economics and markets**

- state of the art and projections

**R&D priorities**

**Crossing the valleys of death**

- from incentive-driven to self-sustained markets
- from technology push to market pull

**Outlook**

*Background photo: www.bso.vvs.be*

# Outlook

- **Cost reduction:** **factor 5**
- **Efficiency enhancement:** **factor 2**
- **Volume increase:** **factor 100-1000**


thank you for your attention!