Energy research Centre of the Netherlands

Photovoltaic solar energy

progress beyond expectations

Wim Sinke

ECN Solar Energy & European Photovoltaic Technology Platform

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

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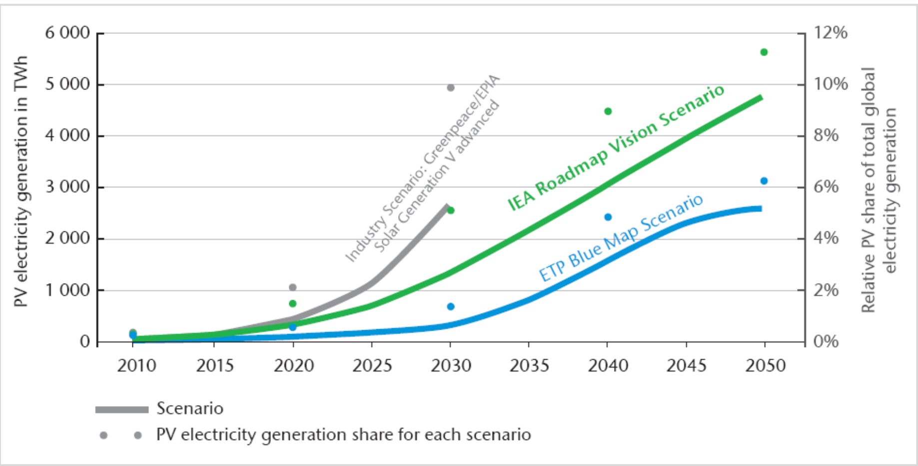
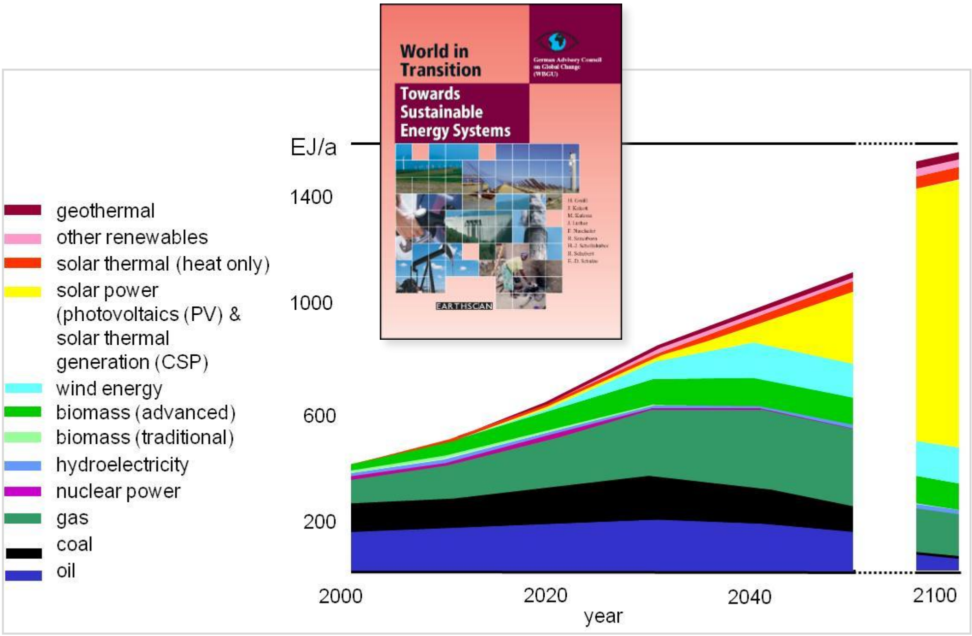
The challenge quantified

- **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)

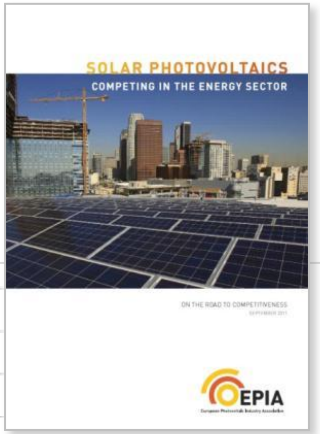
- primarily dependent on annual insolation
- influenced by system quality and design, partial shading, etc.

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

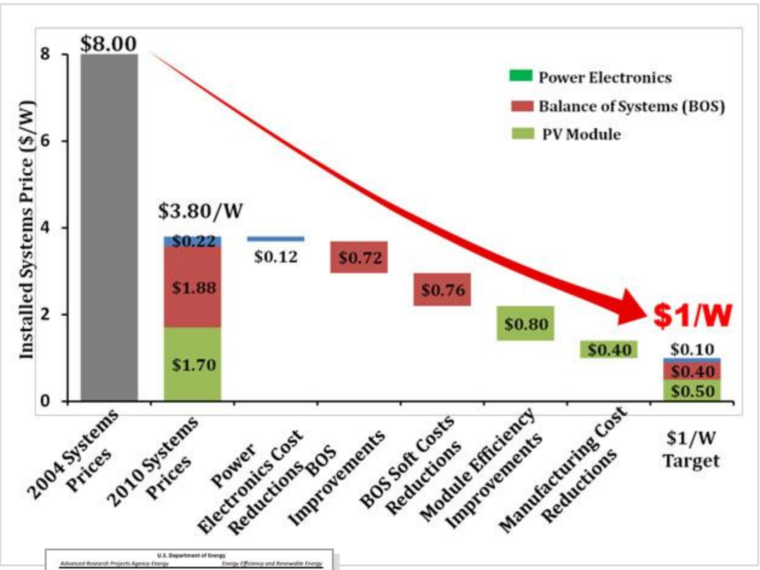
cost of capital:

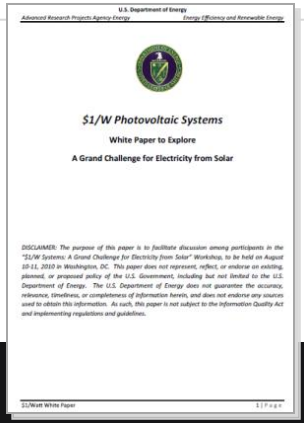
- depreciation time (yr)
- interest rate / Return on Investment required (%)

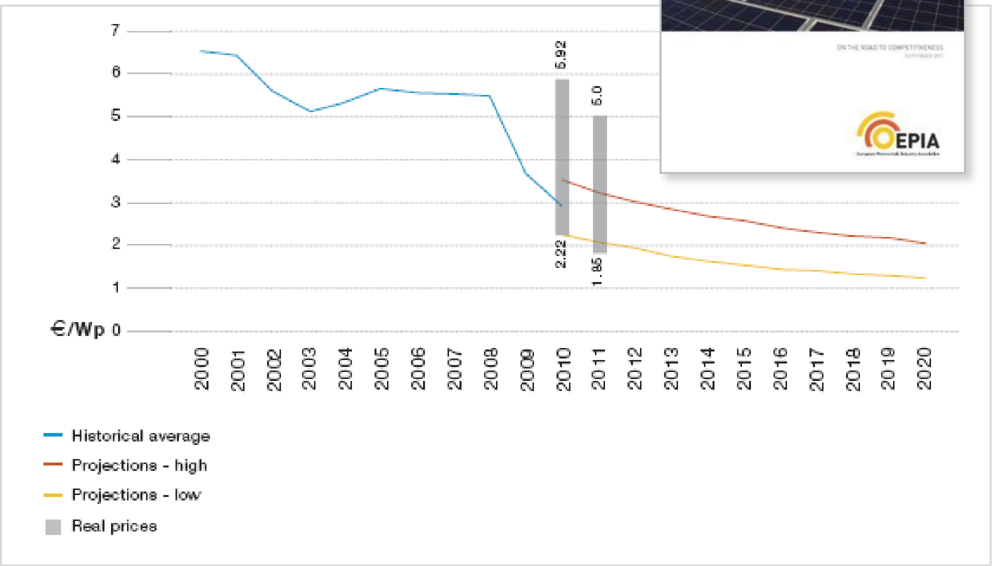
At what cost (price)?



0.05 $/kWh ~ 0.10 €/kWh *(or less)*:





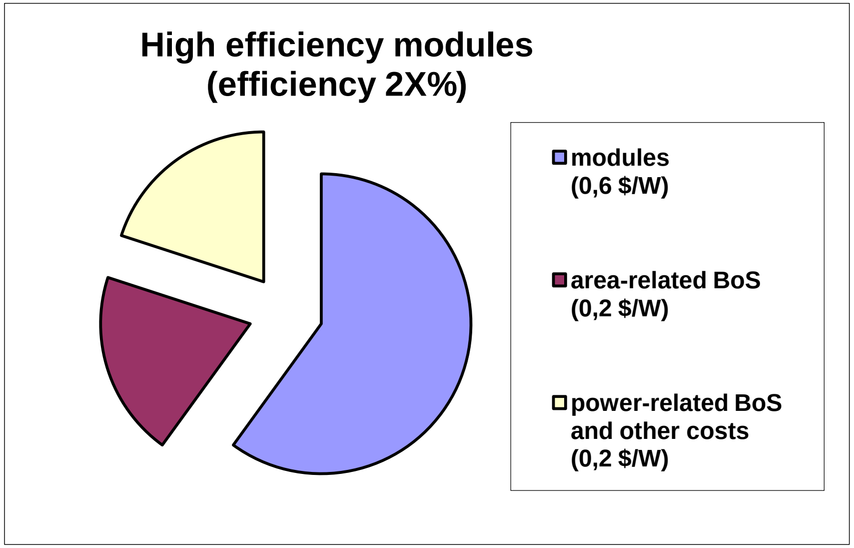


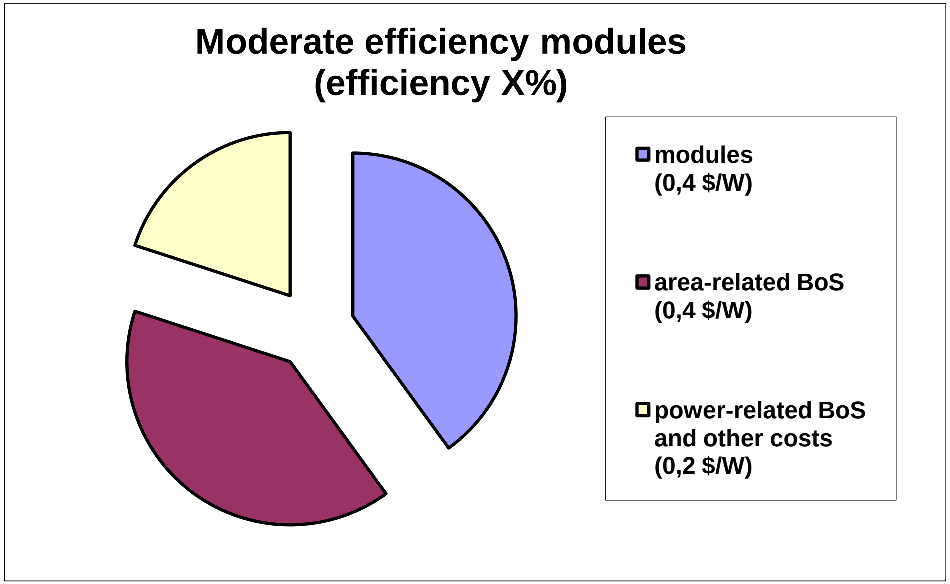
typically

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

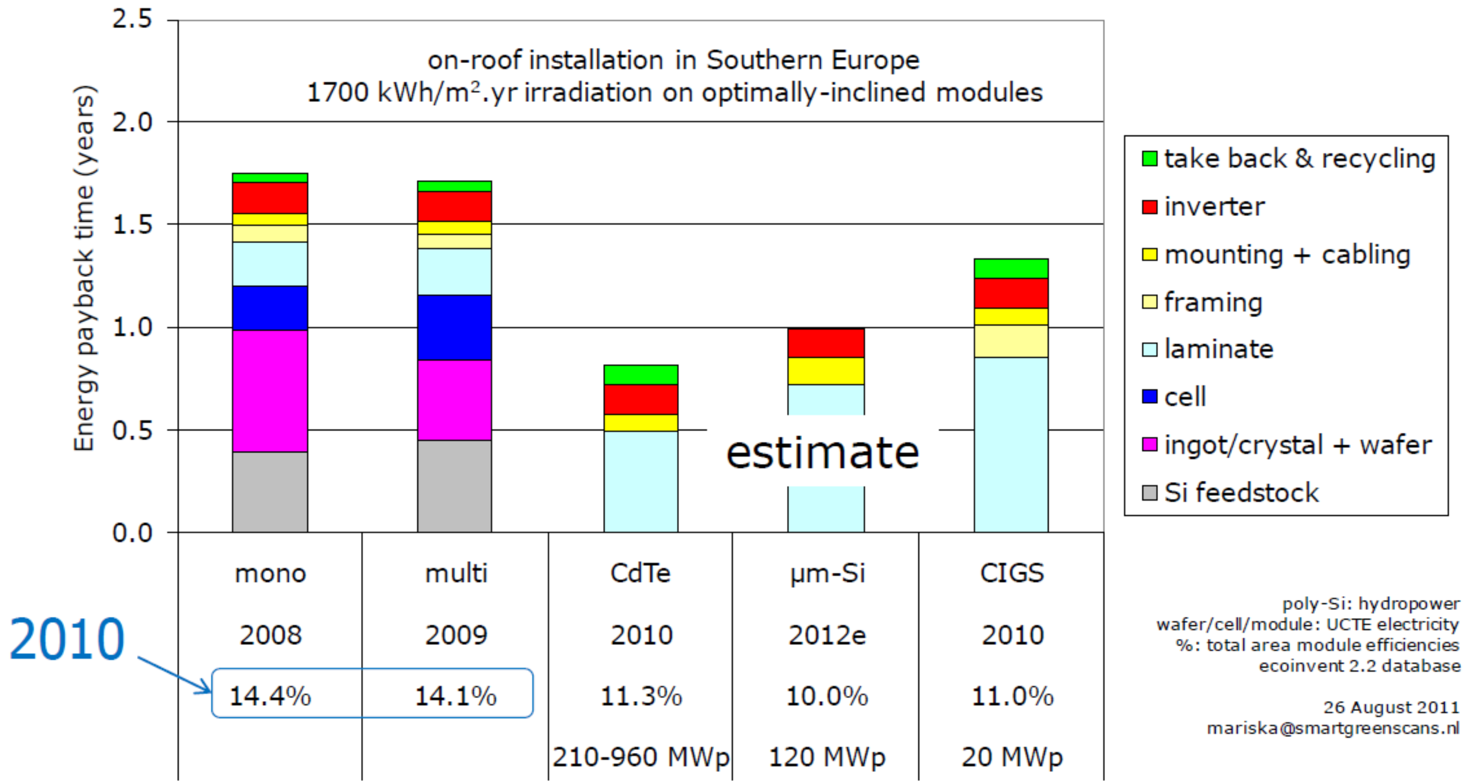
First Solar

Public acceptance: *not to be taken for granted*

Courtesy Michael Marčák

Energy payback time

smart GREEN SCANS



Mariska de Wild-Scholten 8 September 2011 10

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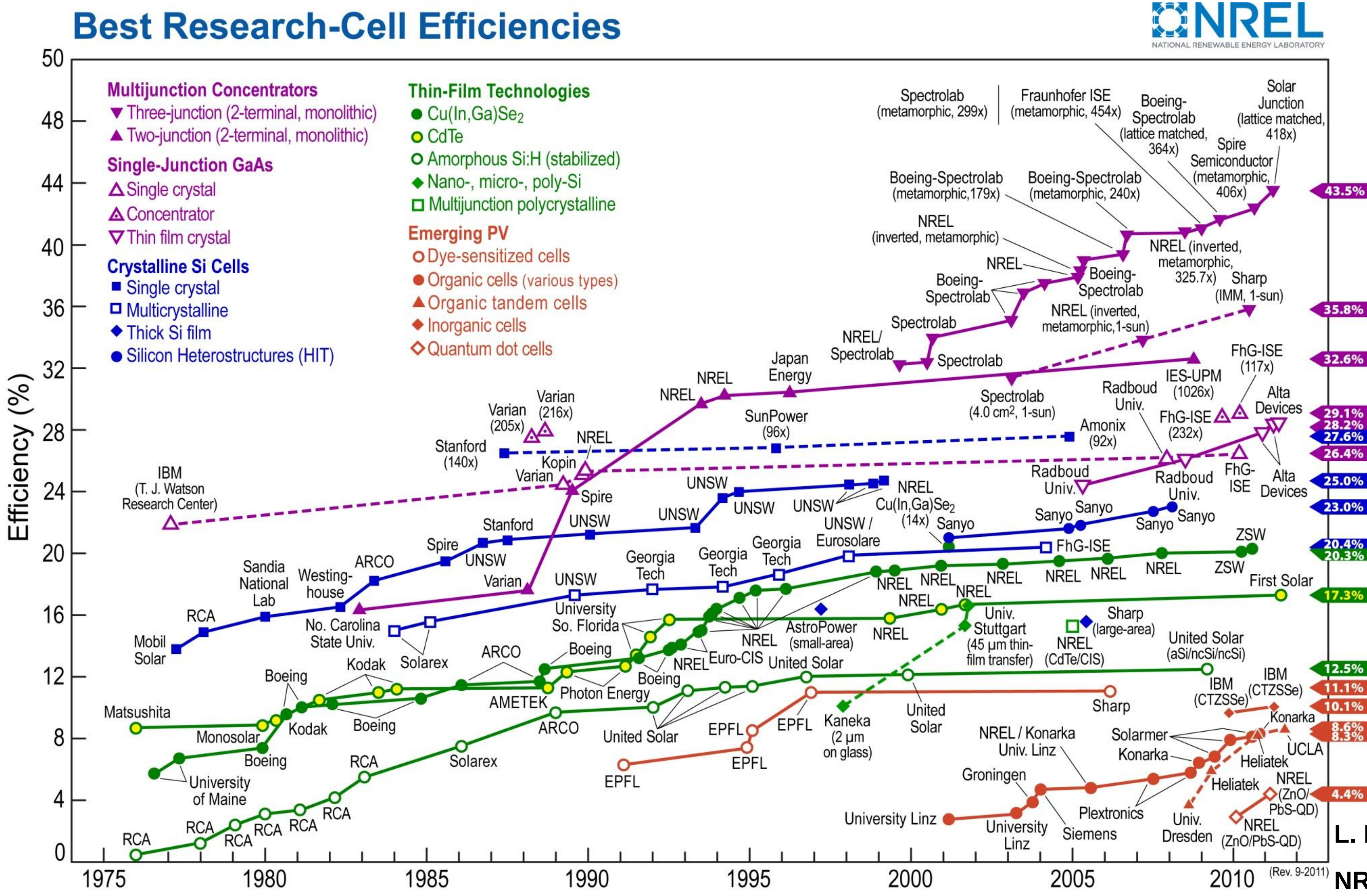
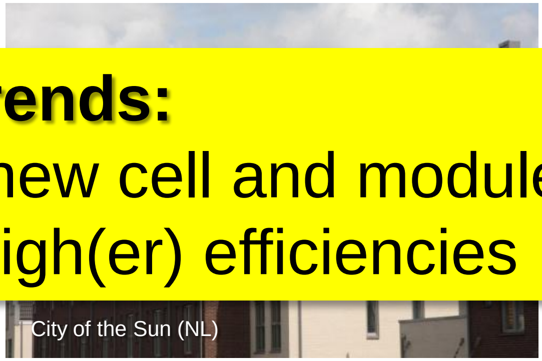


L. Kazmerski
NREL, 2011

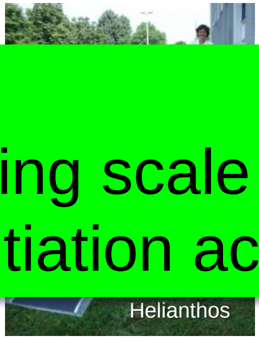
Cell & module technologies

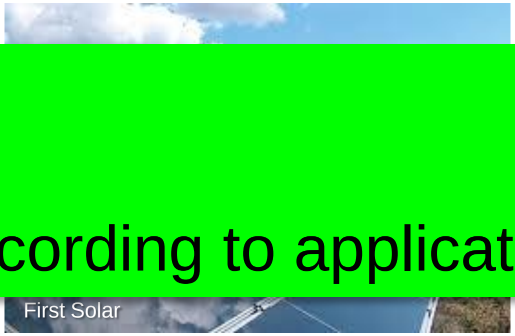


Trends:
- new cell and module architectures
- high(er) efficiencies

<u>Commercial (flat plate):</u>
wafer-based silicon
- monocrystalline
- multicrystalline

Module efficiencies 14 ~ 20%





Trends:
- increasing scale
- differentiation according to application

<u>Commercial (flat plate):</u>
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

<u>oncentrator):</u>
II-V semiconductors

ies 25 ~ 30%

Cell & module technologies

Trends:

- applications of nanotechnology
- synergy with other fields of technology

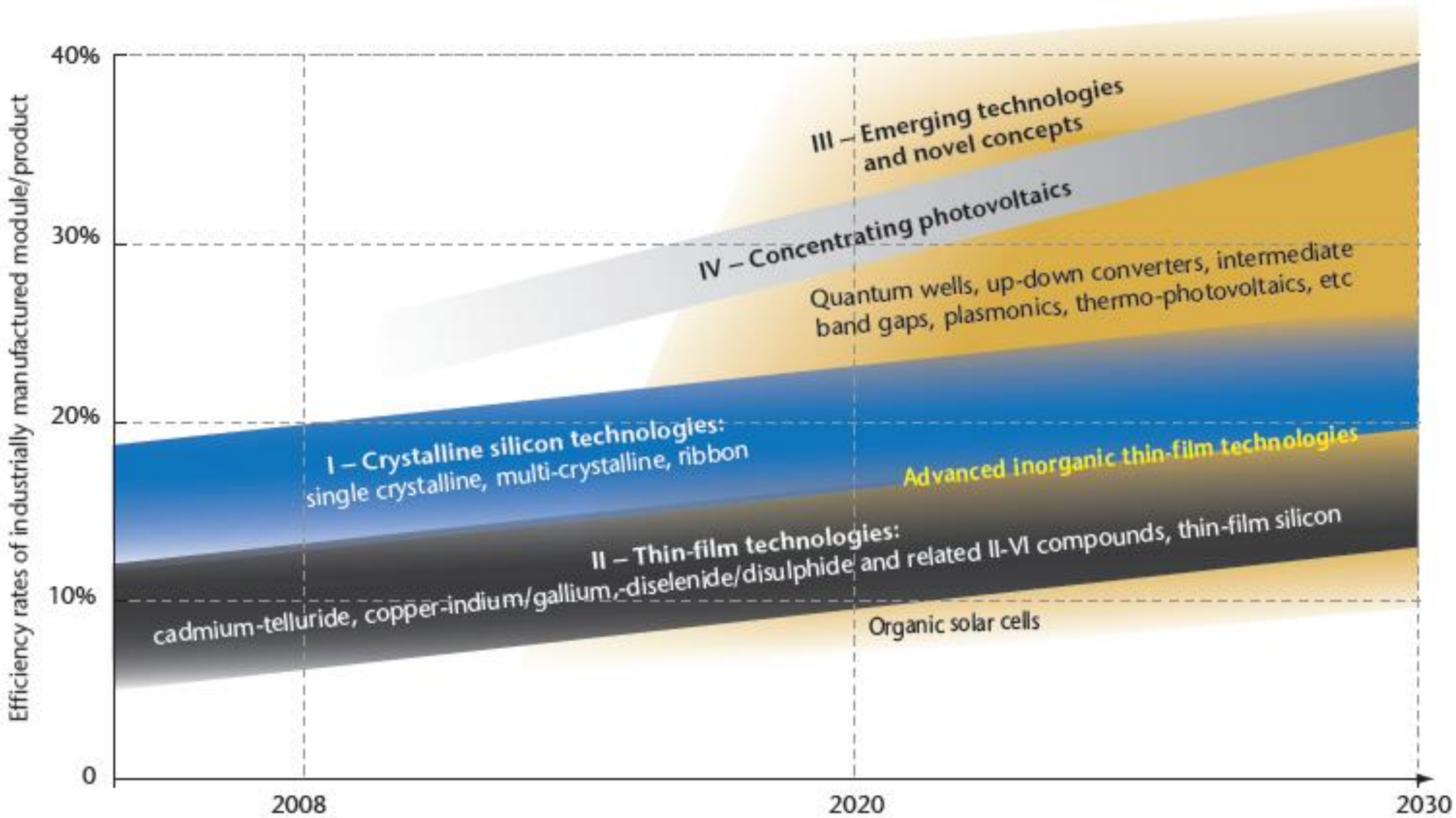
g and novel technologies:

-cost concepts

ogies for new applications)

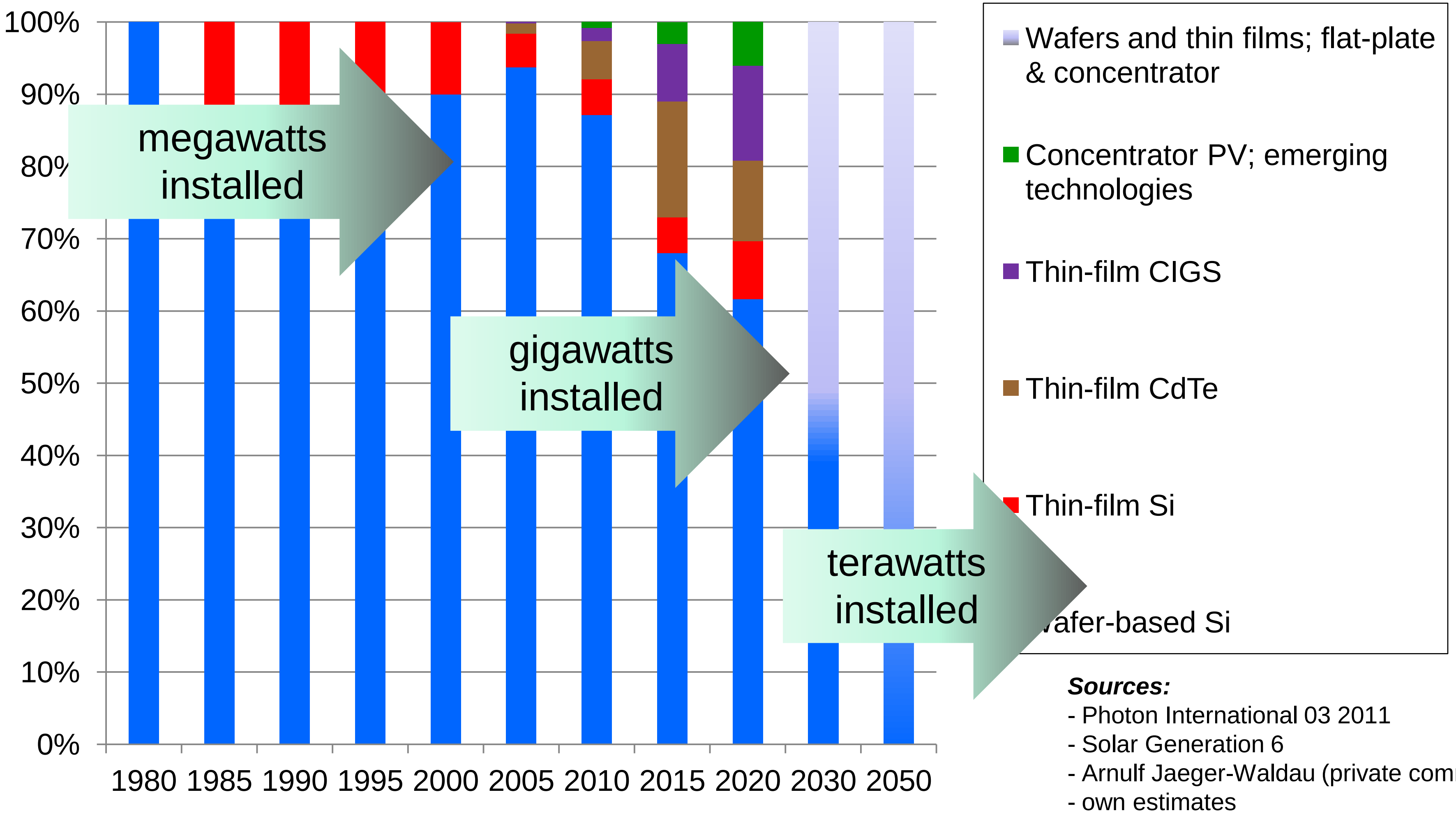
n-efficiency concepts

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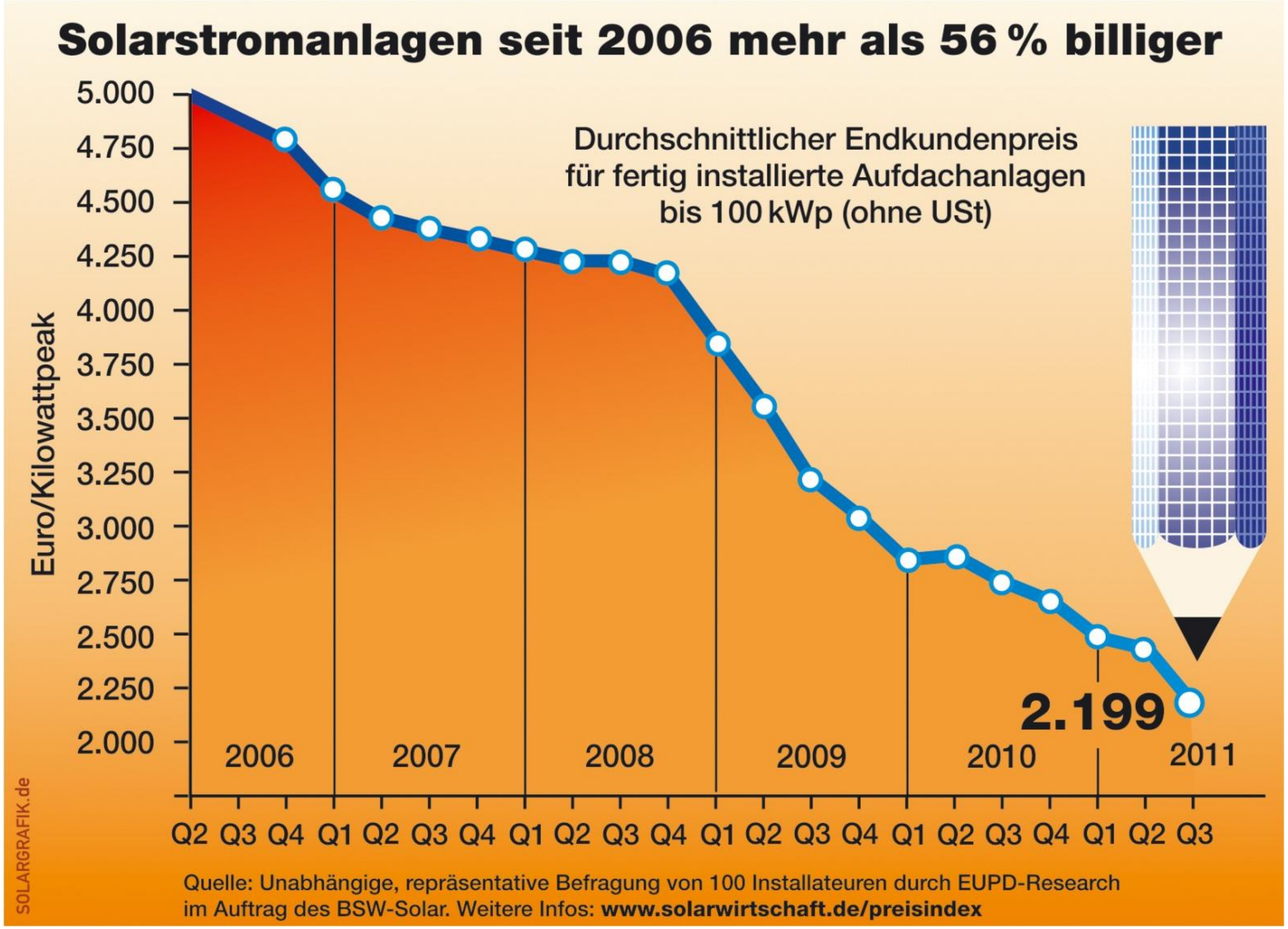
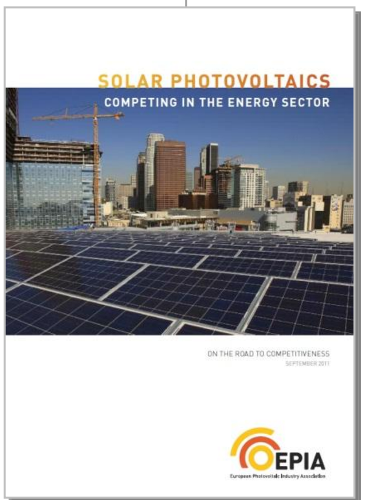
PV system price development – German rooftops
(BSW-Solar, 2011)



Price evolution solar modules (Europe)



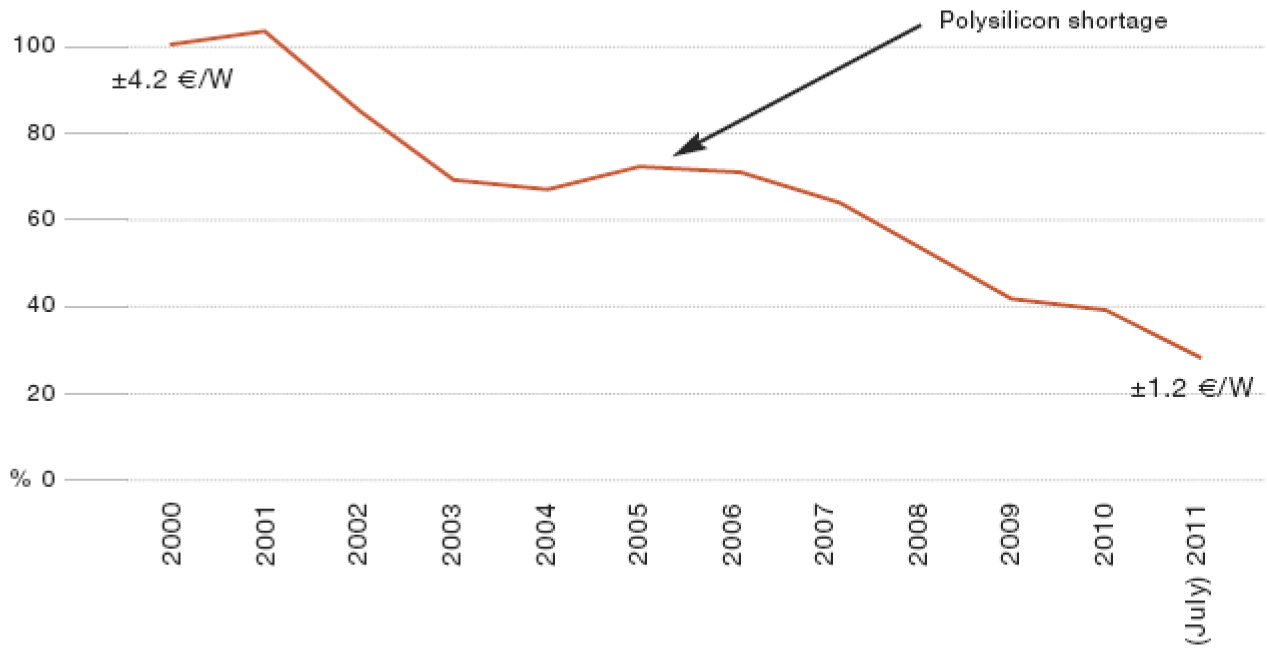
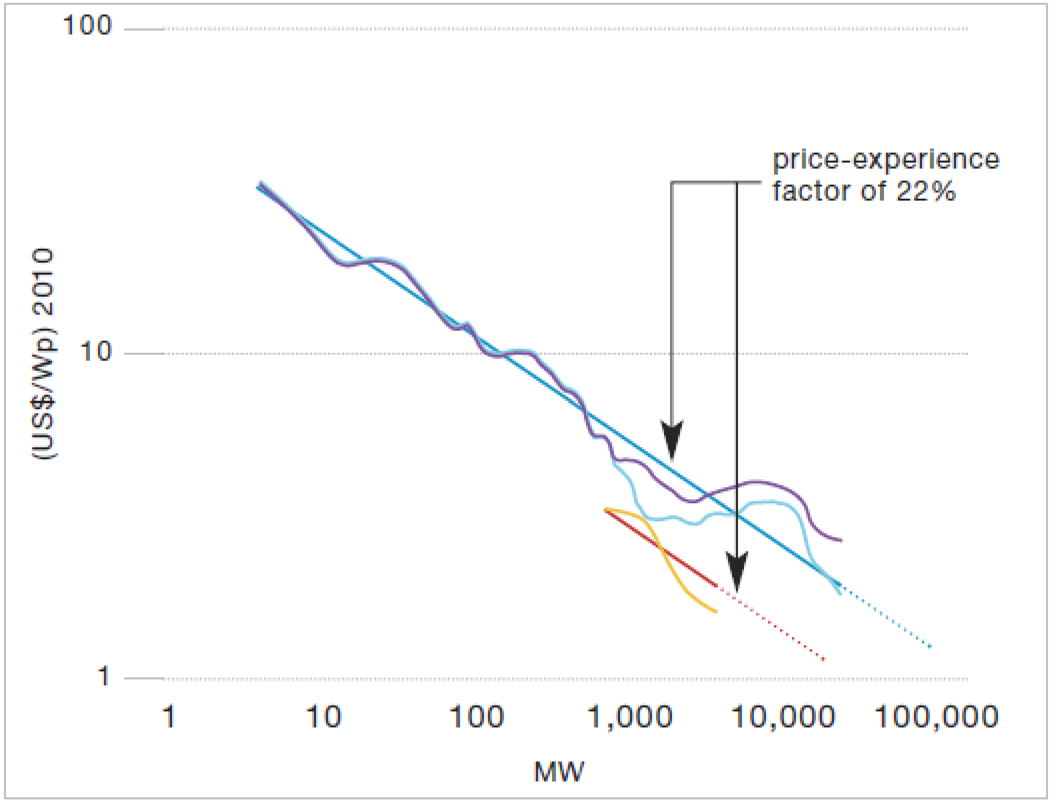


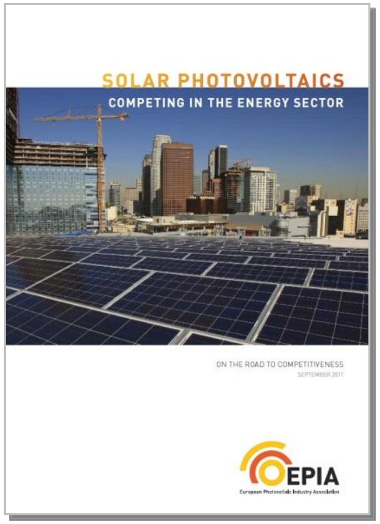
Figure 3 - Evolution of the average PV module price in Europe

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

Price-experience curves solar modules

the combined effect of volume and innovation

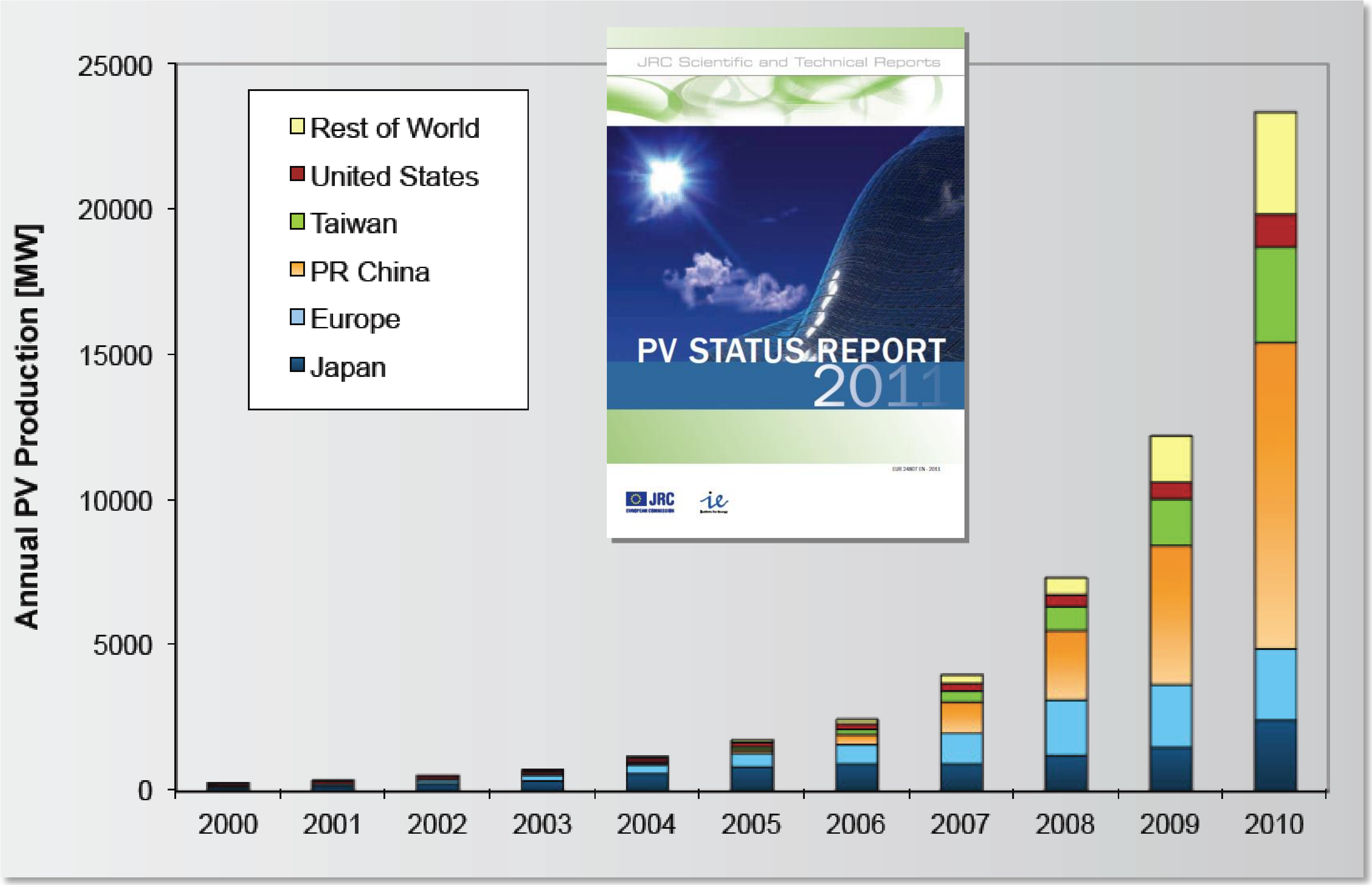




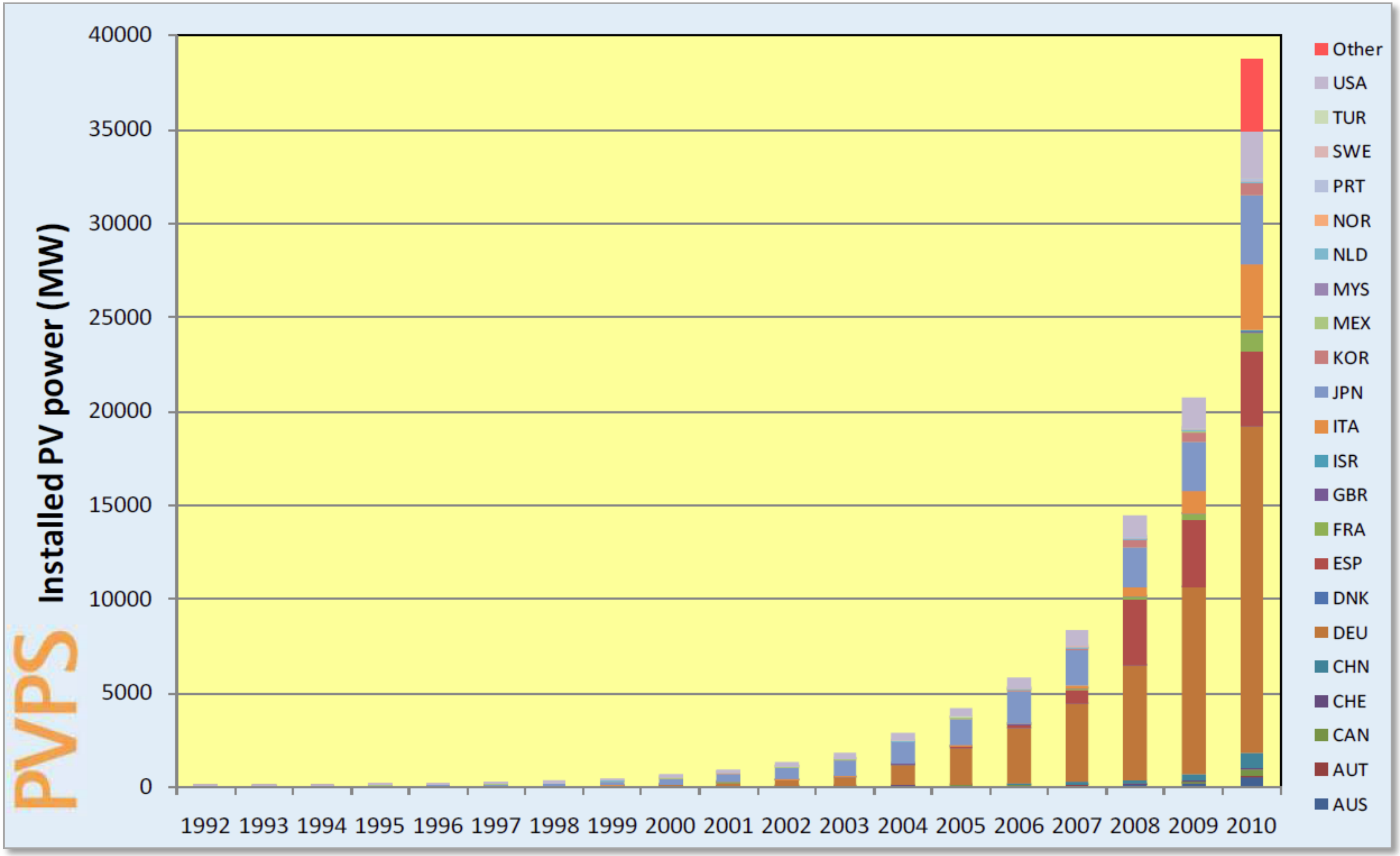
- c-Si LOW
- c-Si HIGH
- c-Si TREND
- TF
- TF TREND

source: Navigant Consulting, EPIA.

PV cell and module production

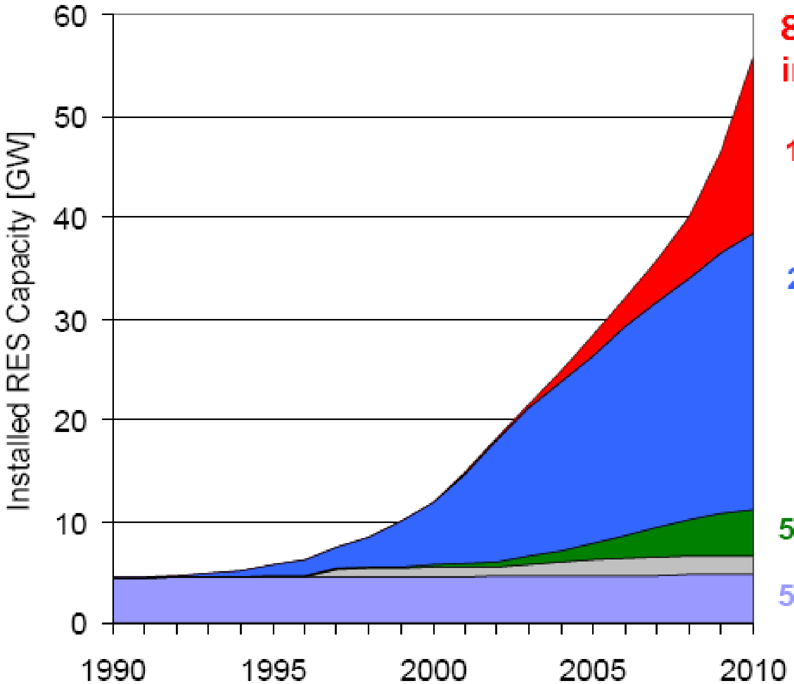


Cumulative installed capacity (IEA PVPS, 2011)



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

17 GW PV

27 GW Wind

5 GW Biomass

5 GW Hydro

Data Source: BMU, March 2011

Courtesy M. Lippert,

SAFT

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

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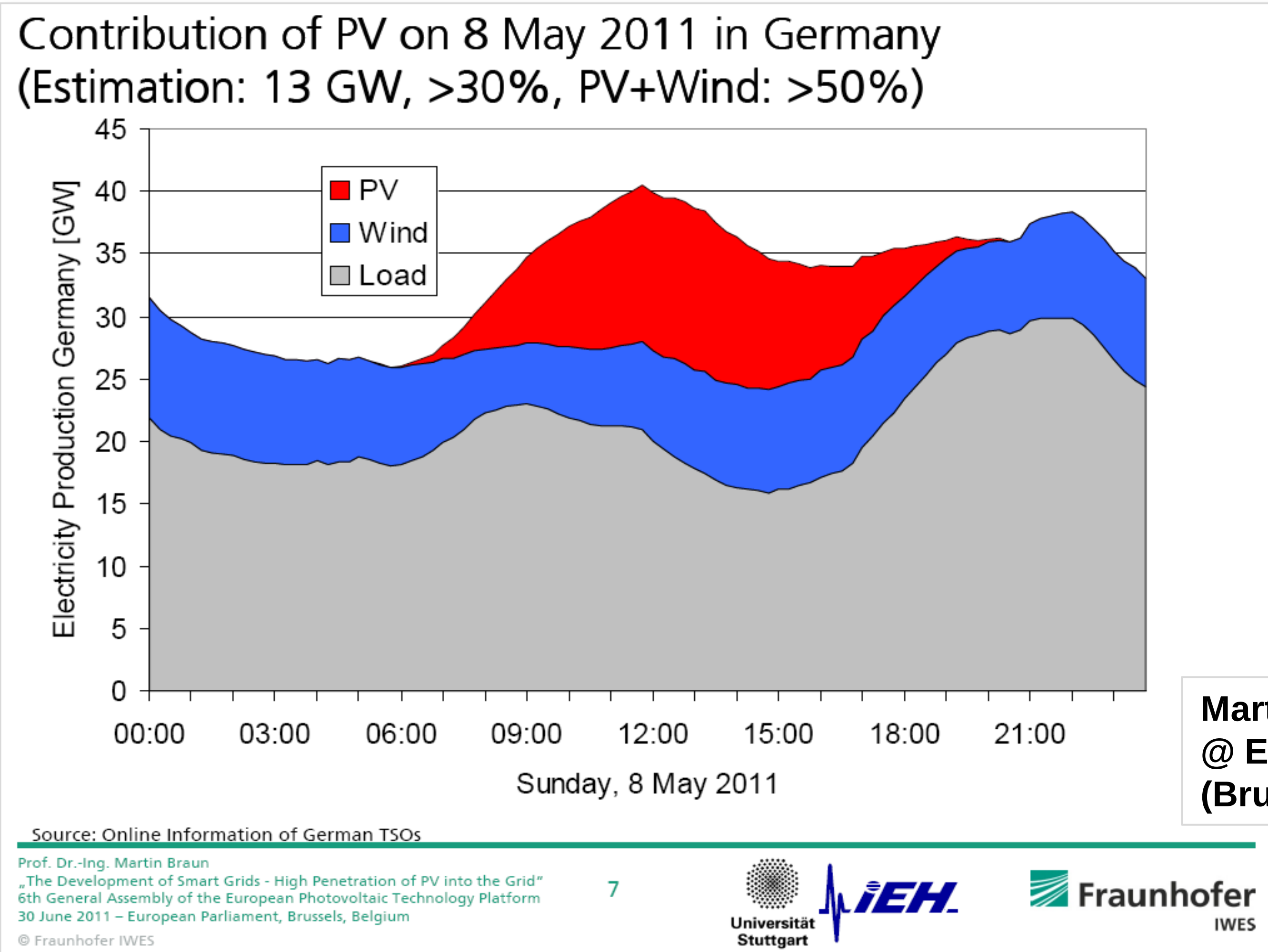
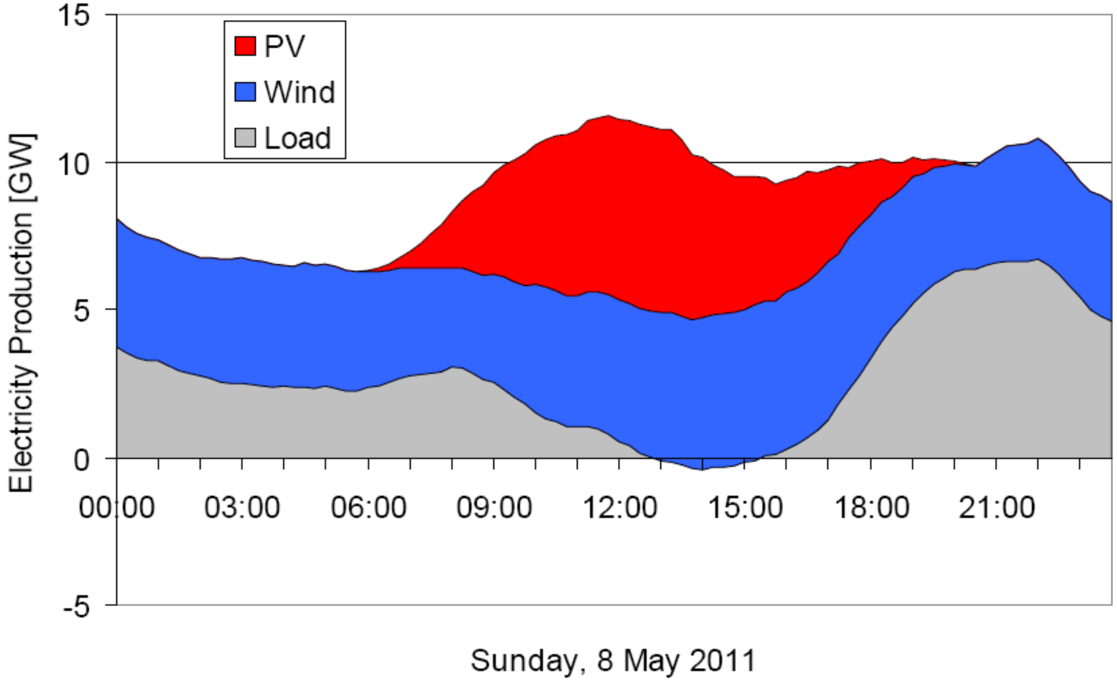
PV is far beyond a niche already



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

PV is far beyond a niche already

Contribution of PV on 8 May 2011 in TenneT control area
(Estimation: 6 GW, > 50%, PV+Wind: > 100%)



Source: http://www.tennettso.de

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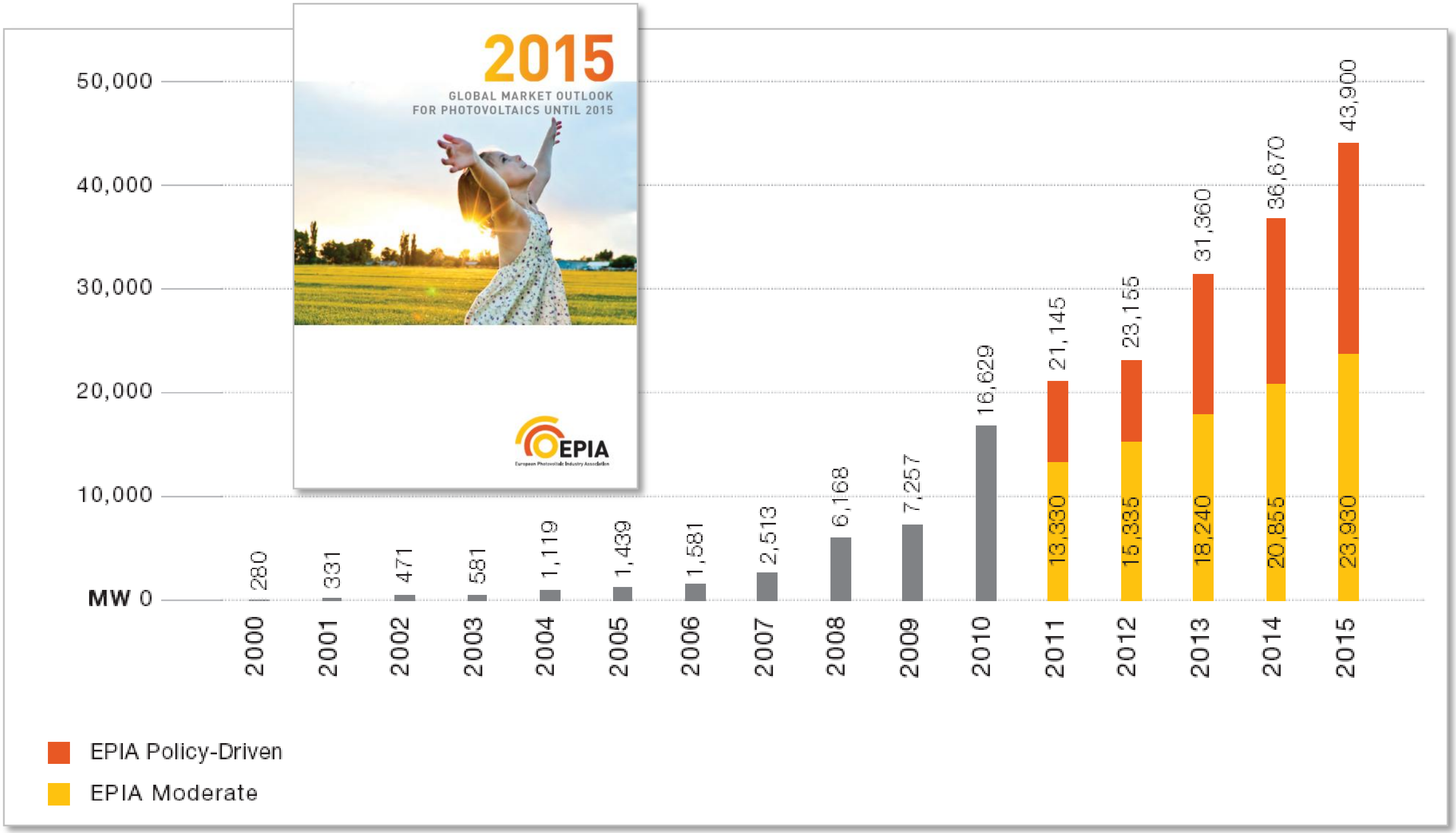
Projected annual installed capacity (EPIA, May 2011)

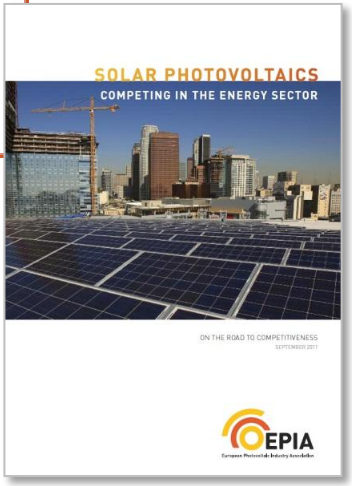


A competitive solution well before 2020

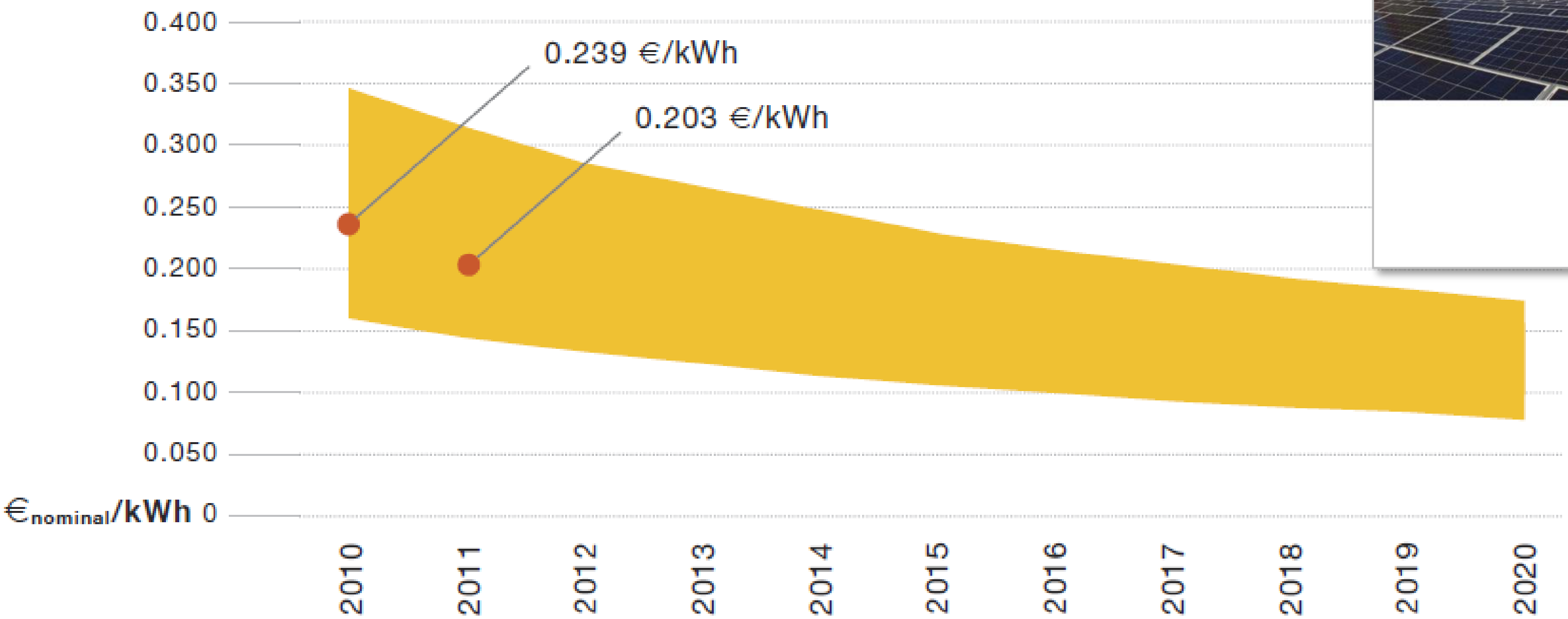
Competitiveness is analysed by comparing PV's generation cost with the PV revenues (dynamic grid parity) and/or with the generation cost of other electricity sources (generation value competitiveness).

"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)



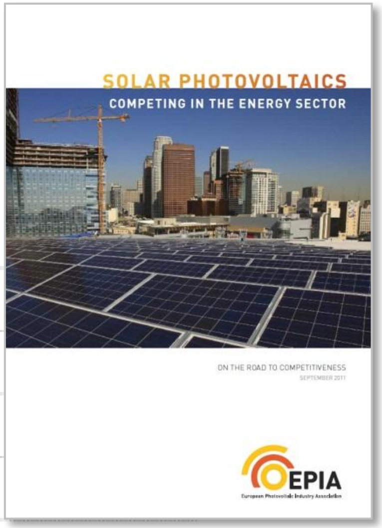


Figure 7 - European PV LCOE range projection 2010-2020

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

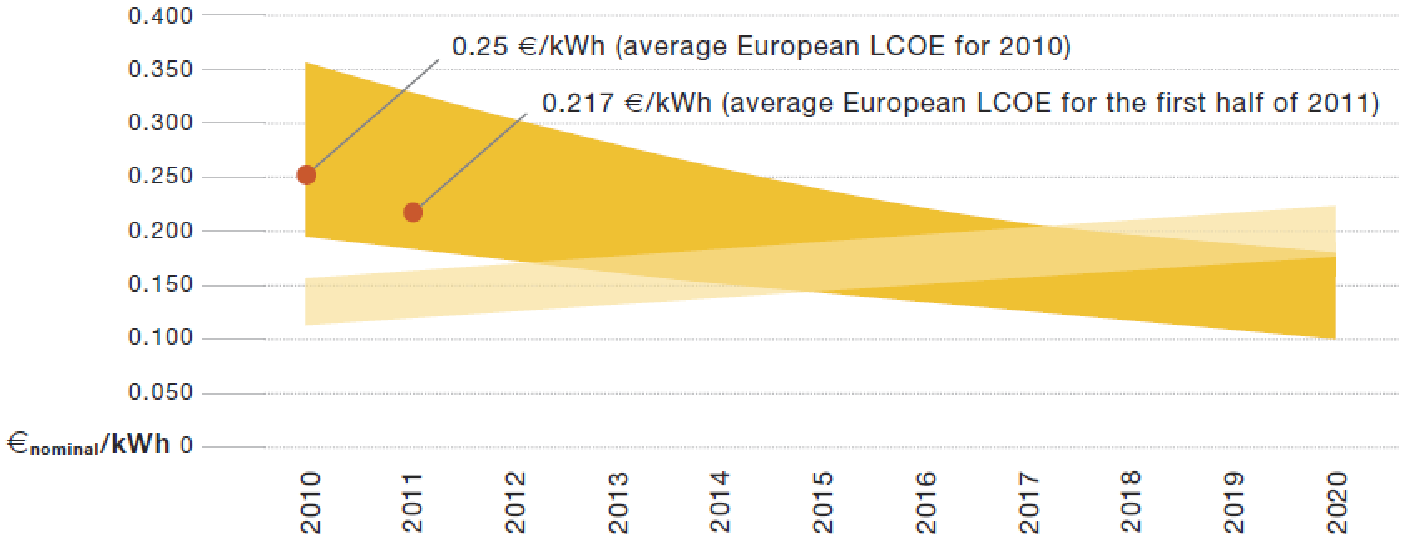
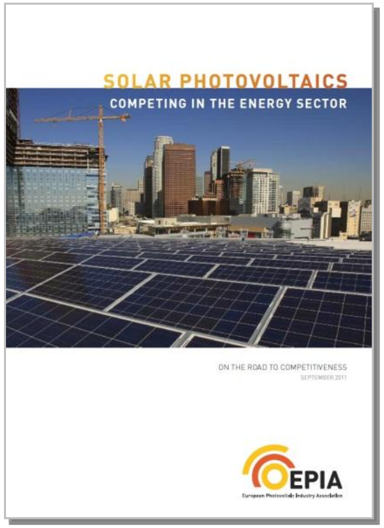


Figure 12A - Dynamic grid parity for residential PV systems in Europe



Competitive position solar electricity (“dynamic grid parity”): *power plants (CCGT)*

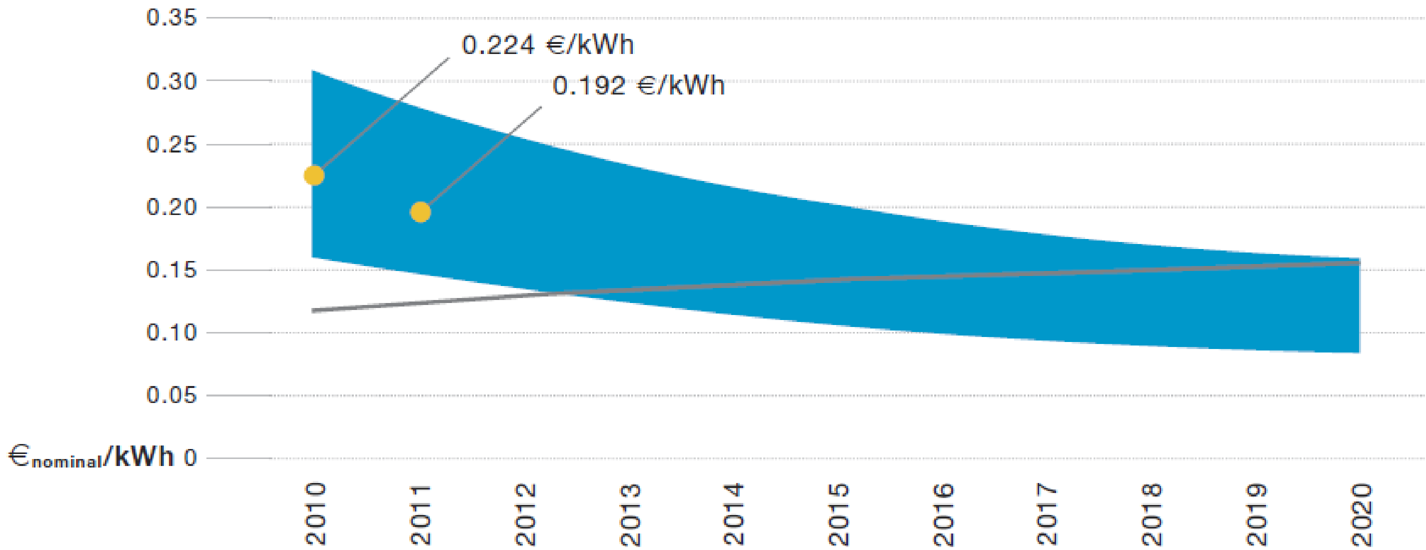
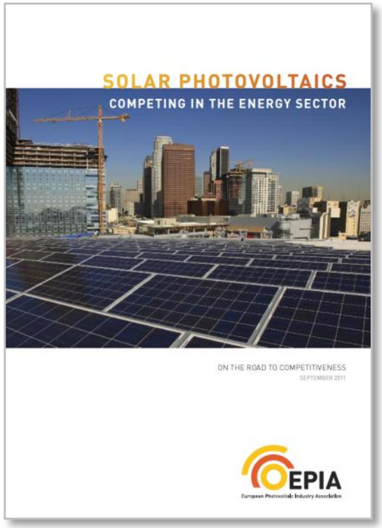


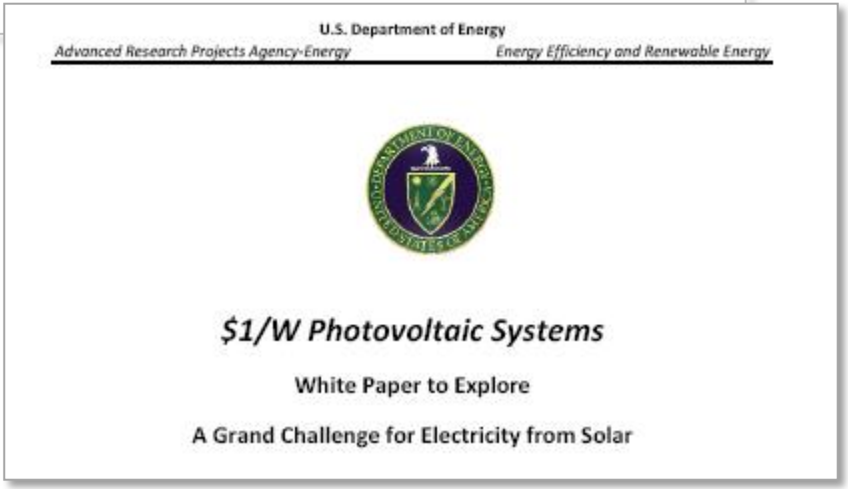
Figure 12D - Generation value competitiveness of large ground-mounted applications in Europe (comparison with CCGT power plant)



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

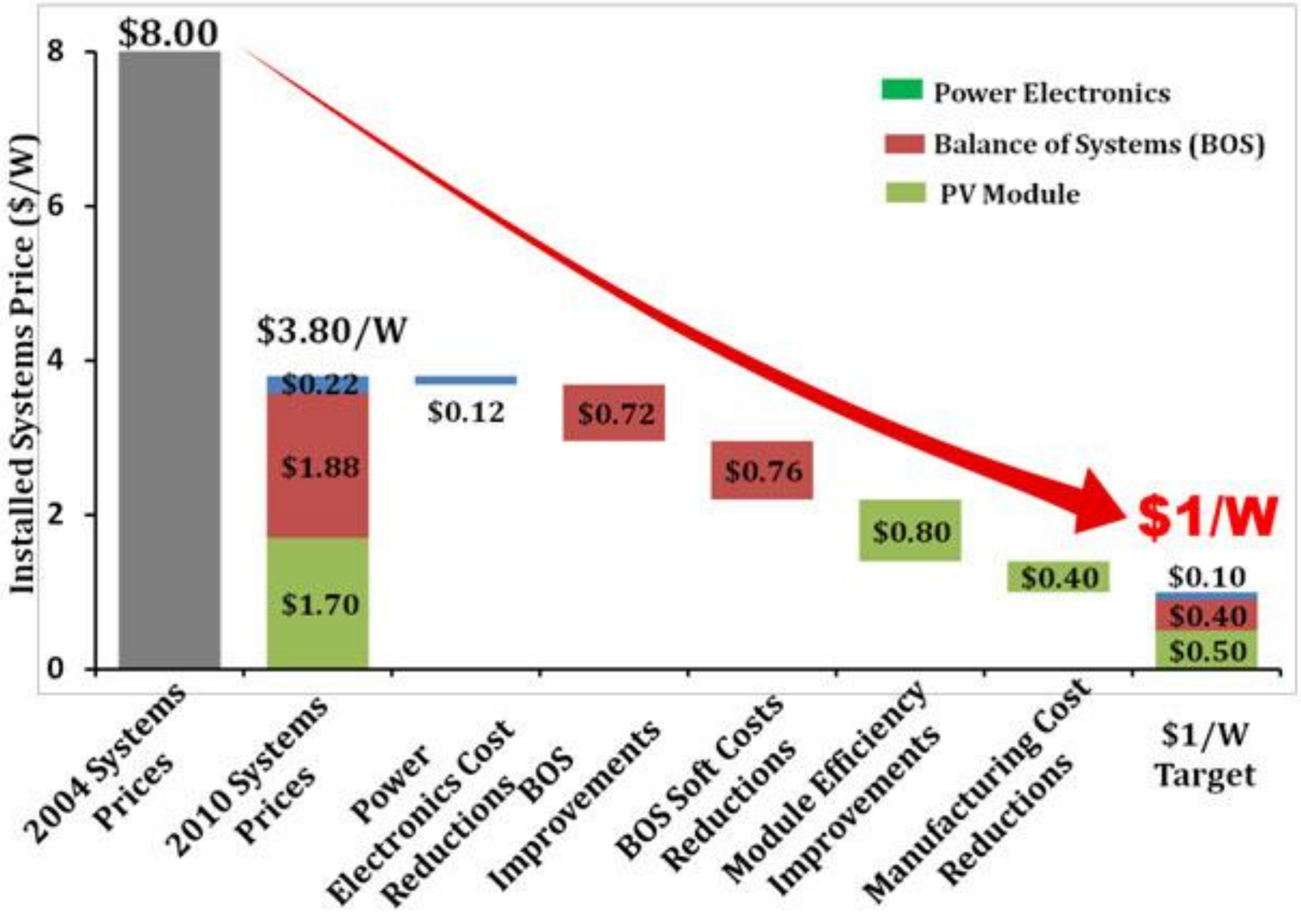
$1/W Photovoltaic Systems

White Paper to Explore

A Grand Challenge for Electricity from Solar

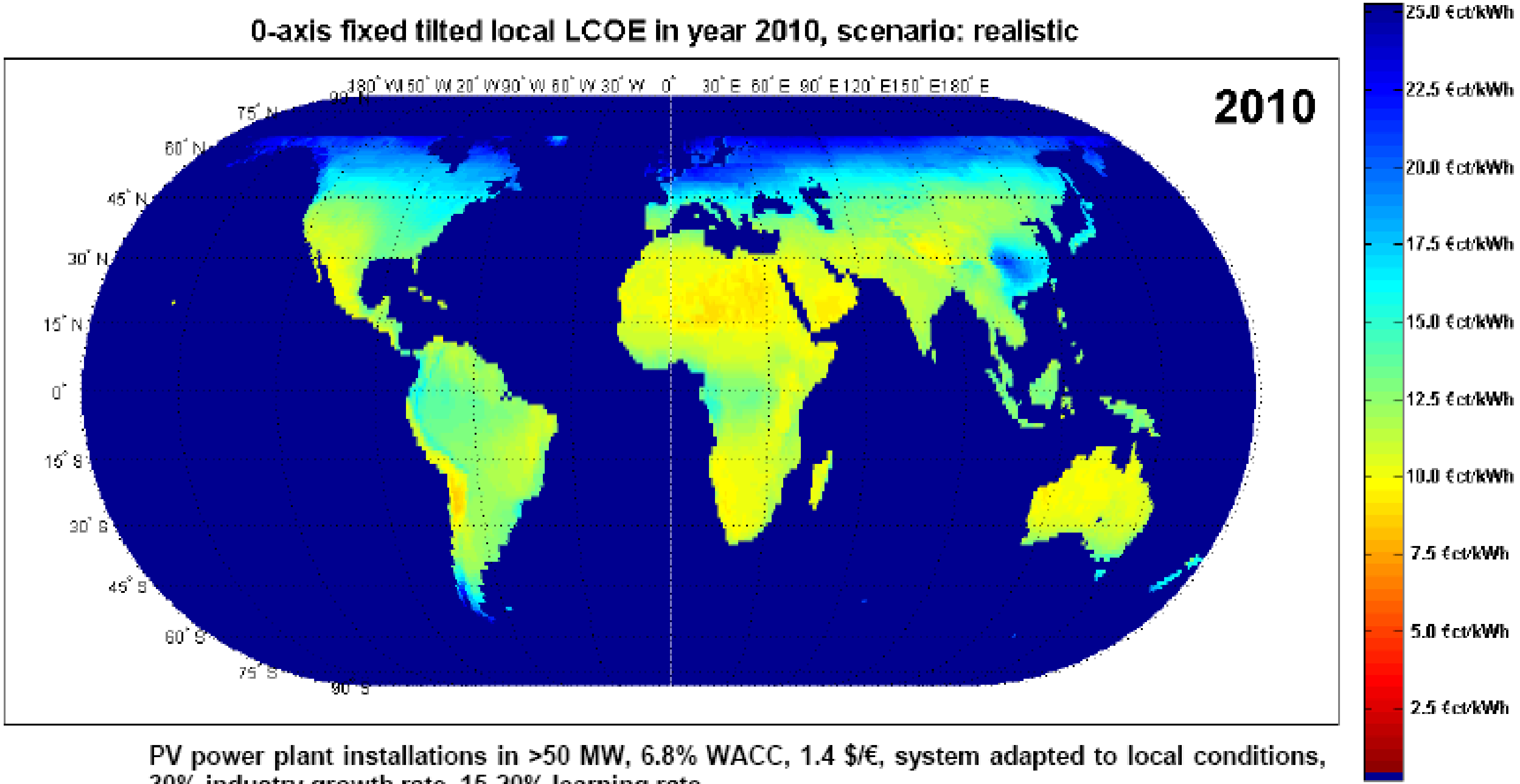
USA DoE SunShot Initiative

Cost-competitive utility-scale PV by 2020



PV Cost Dynamics

Christian Breyer
@ EUPVSEC26
(Hamburg, 2011)



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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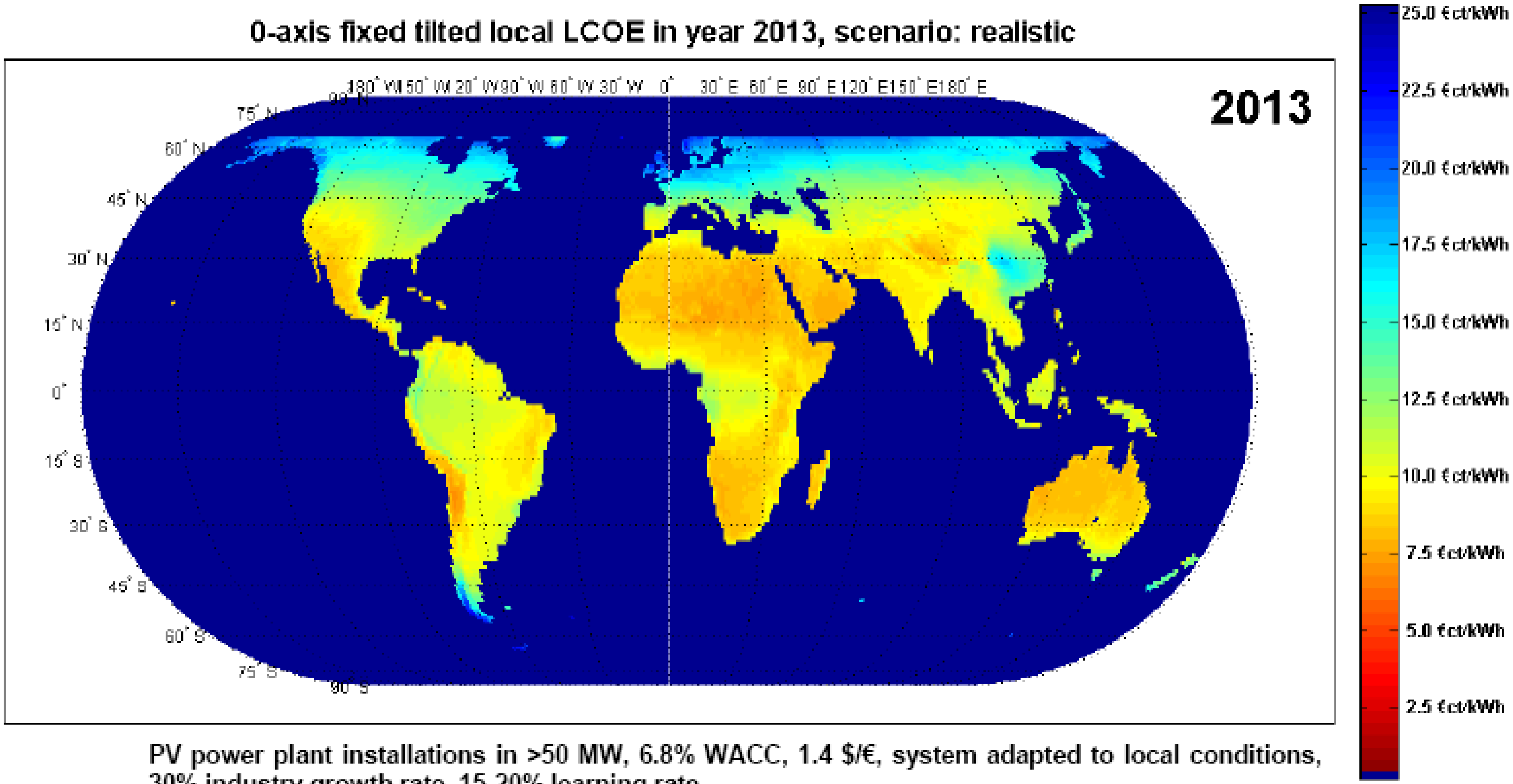

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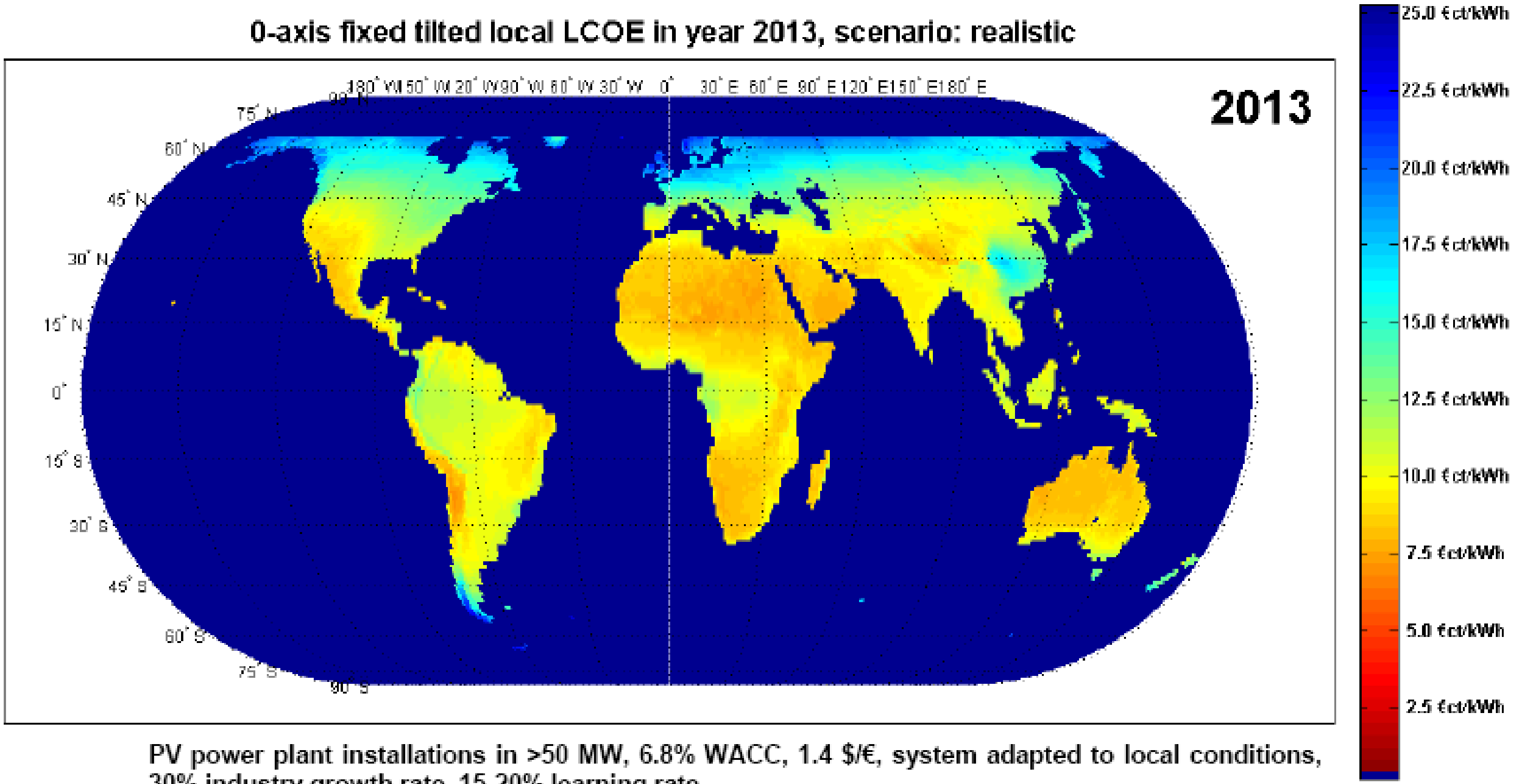

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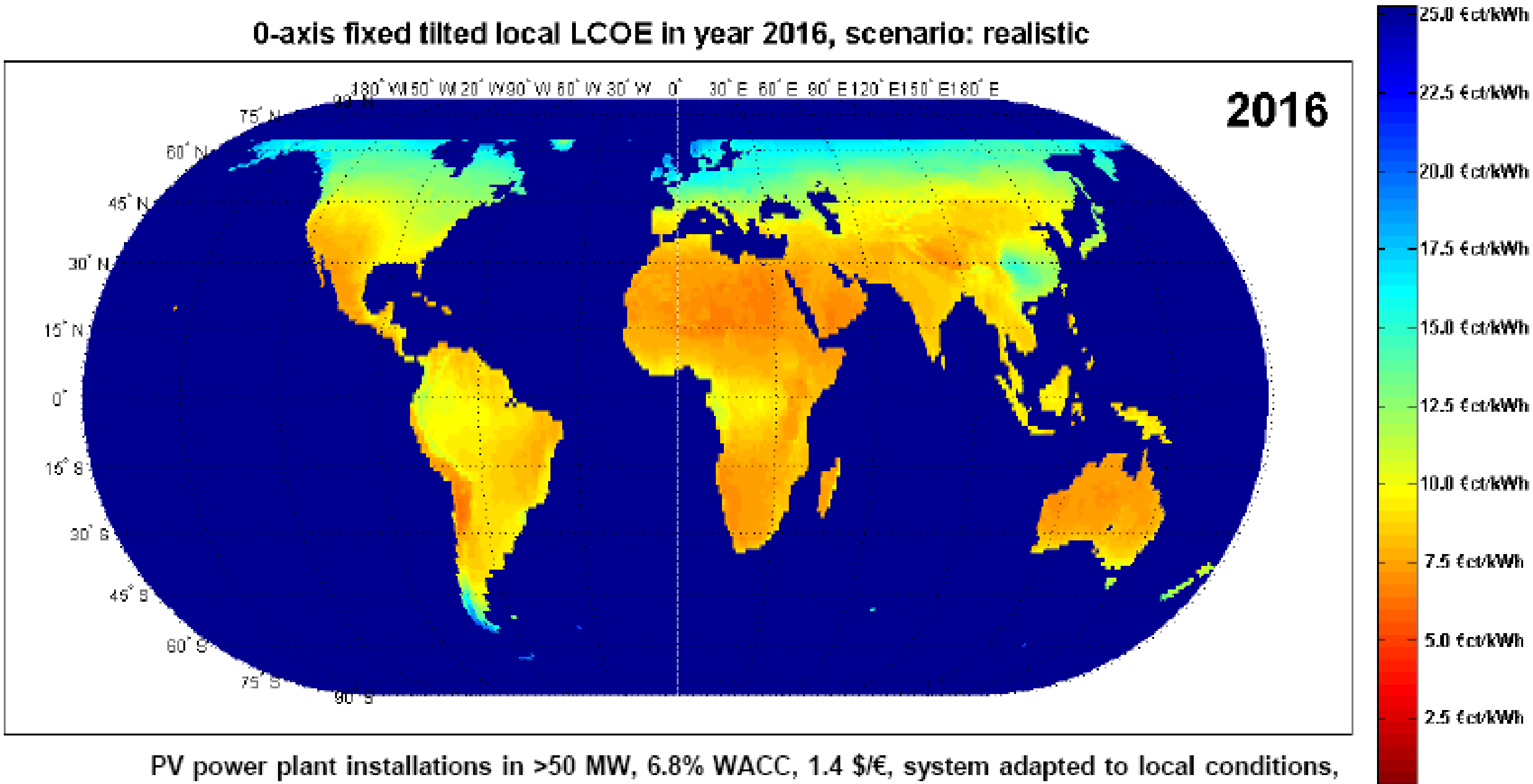
Christian Breyer
@ EUPVSEC26
(Hamburg, 2011)

0-axis fixed tilted local LCOE in year 2016, scenario: realistic



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PV Cost Dynamics

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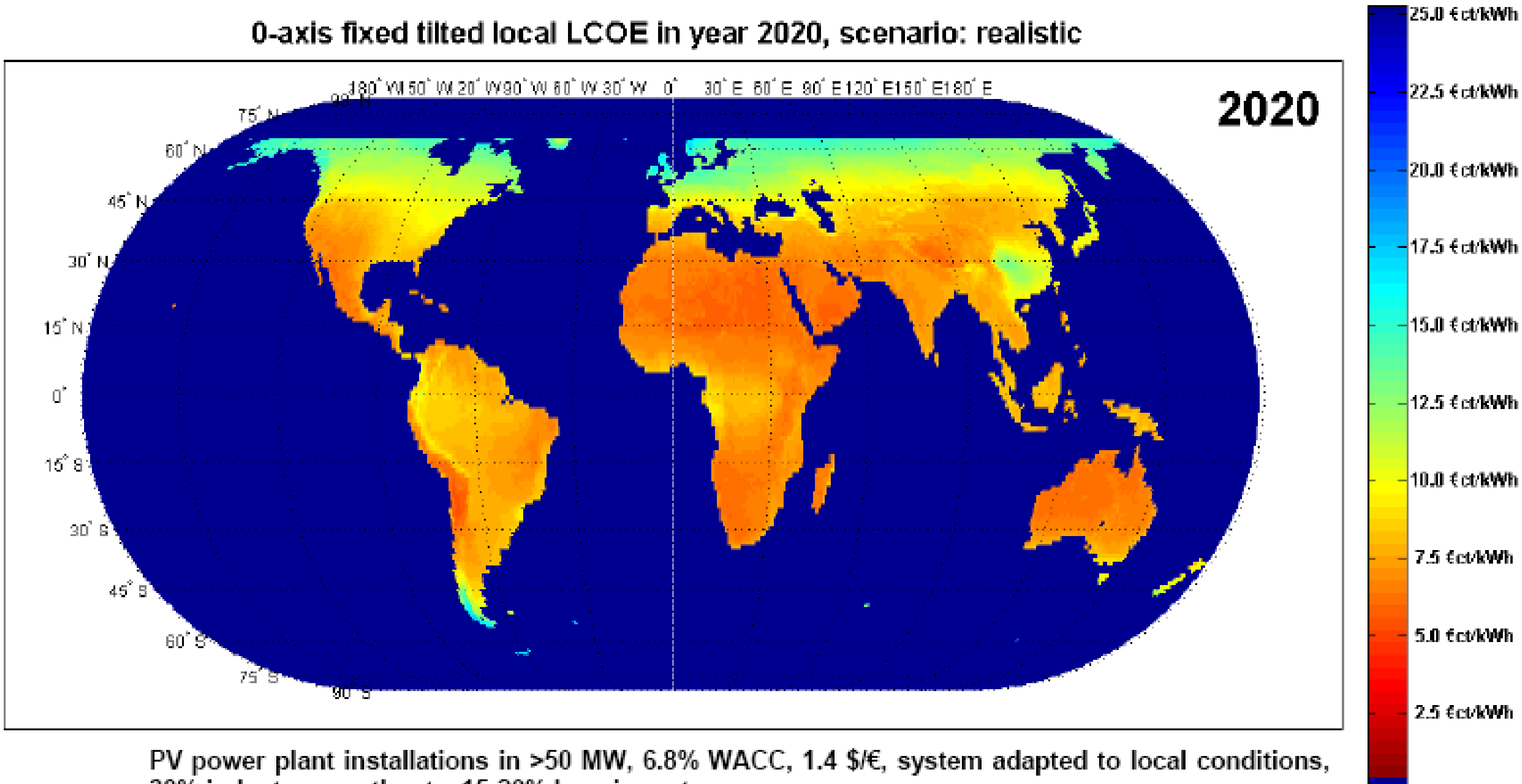
0-axis fixed tilted local LCOE in year 2020, scenario: realistic



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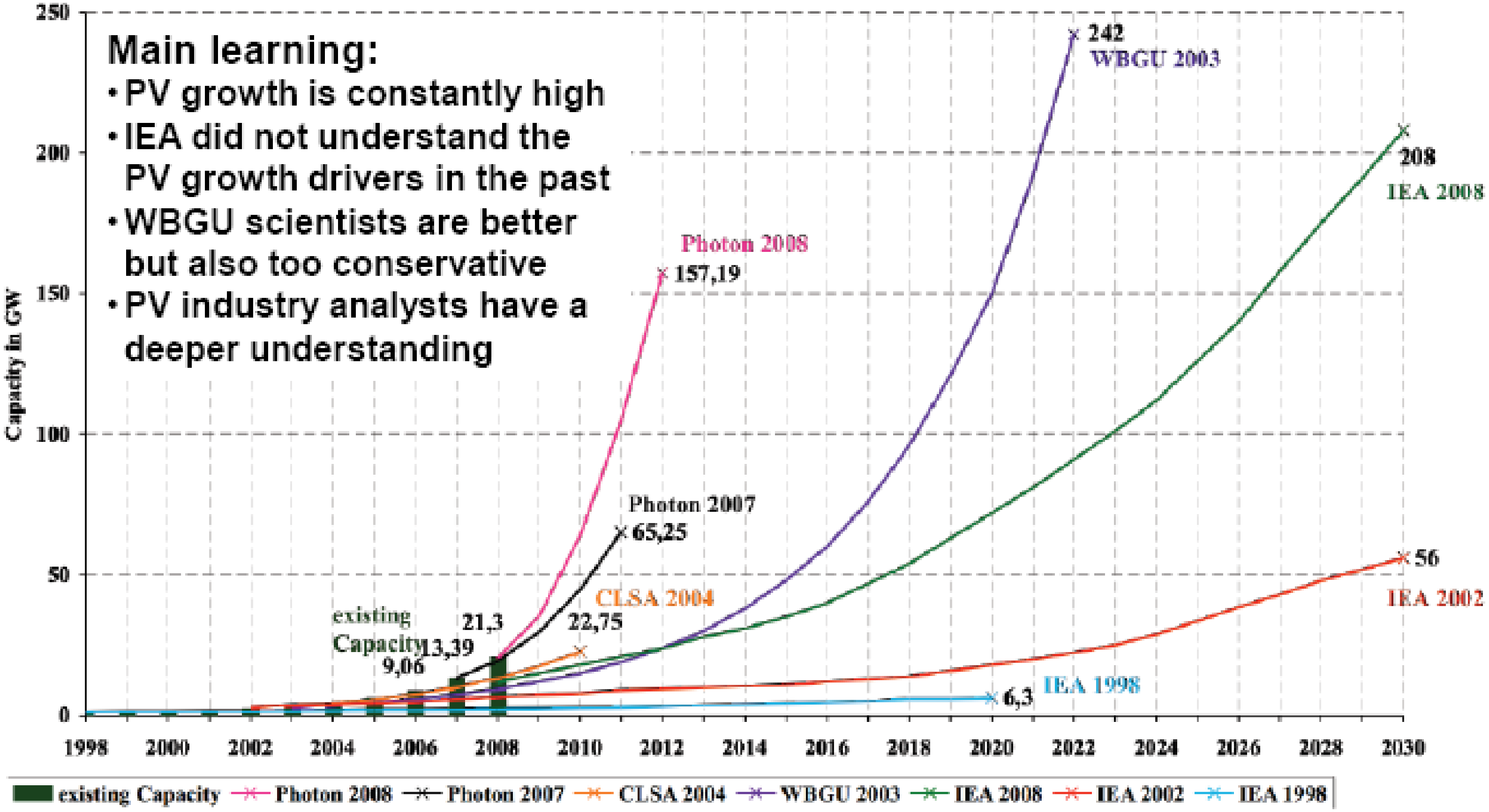
PV Scenarios in the Past

Christian
Breyer
@ EUPVSEC26
(Hamburg, 2011)

Main learning:

- PV growth is constantly high
- IEA did not understand the PV growth drivers in the past
- WBGU scientists are better but also too conservative
- PV industry analysts have a deeper understanding



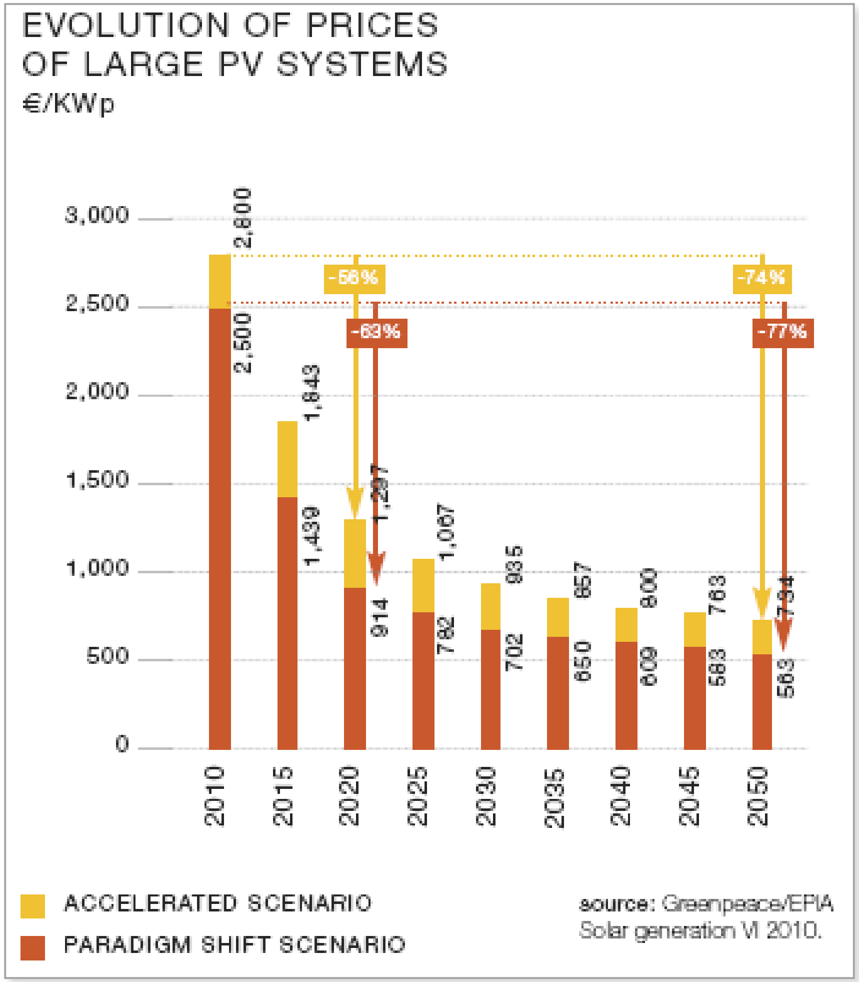
source: Gredler C., 2008. Das Wachstumspotenzial der Photovoltaik und der Windkraft – divergierende Wahrnehmungen zentraler Akteure, Diploma thesis, University Salzburg

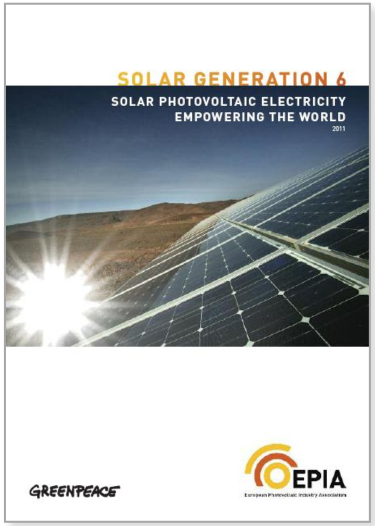
Conclusions

- 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)

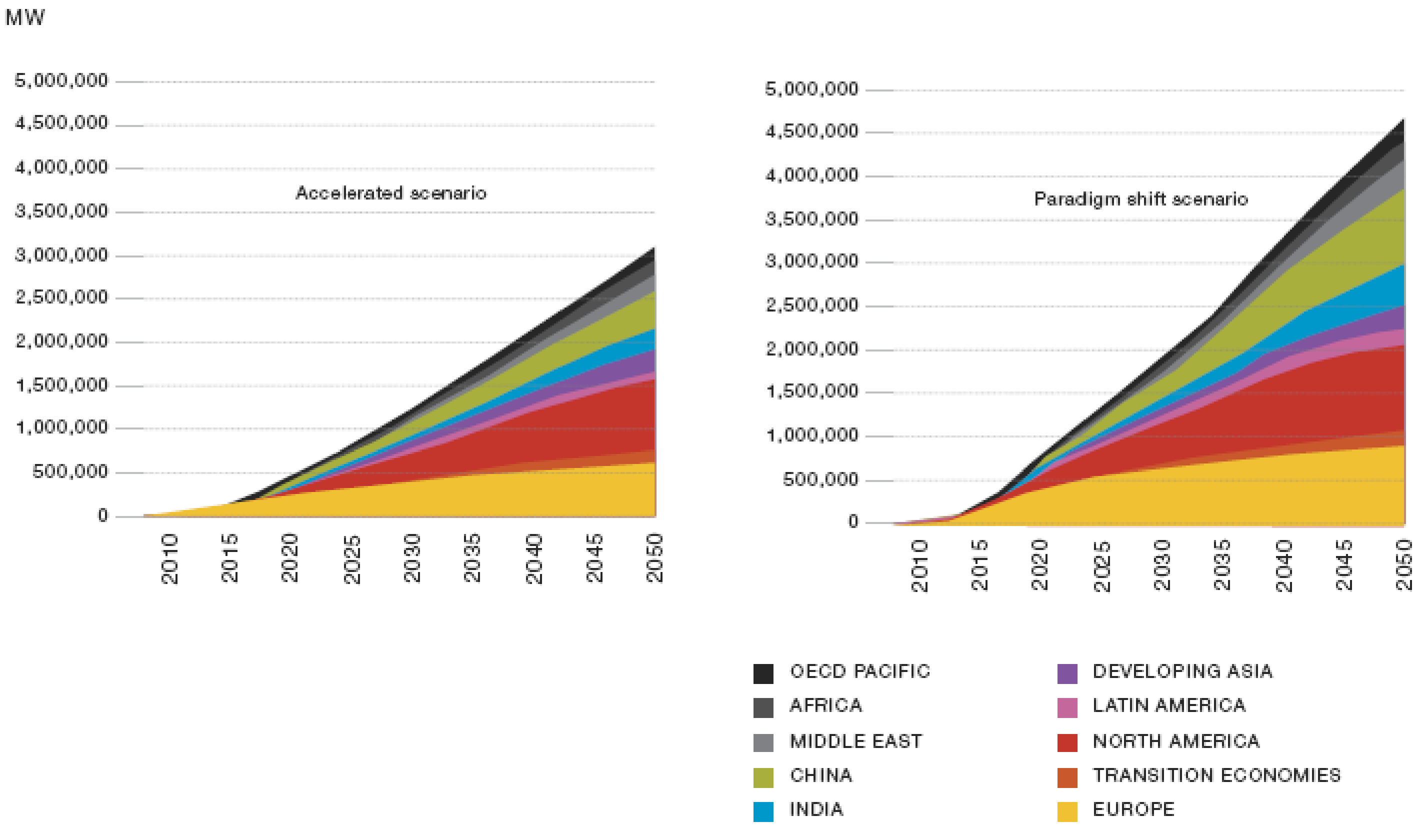
Solar Generation 6

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

ECN

PhotoVoltaic Technology Platform

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						

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

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%

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

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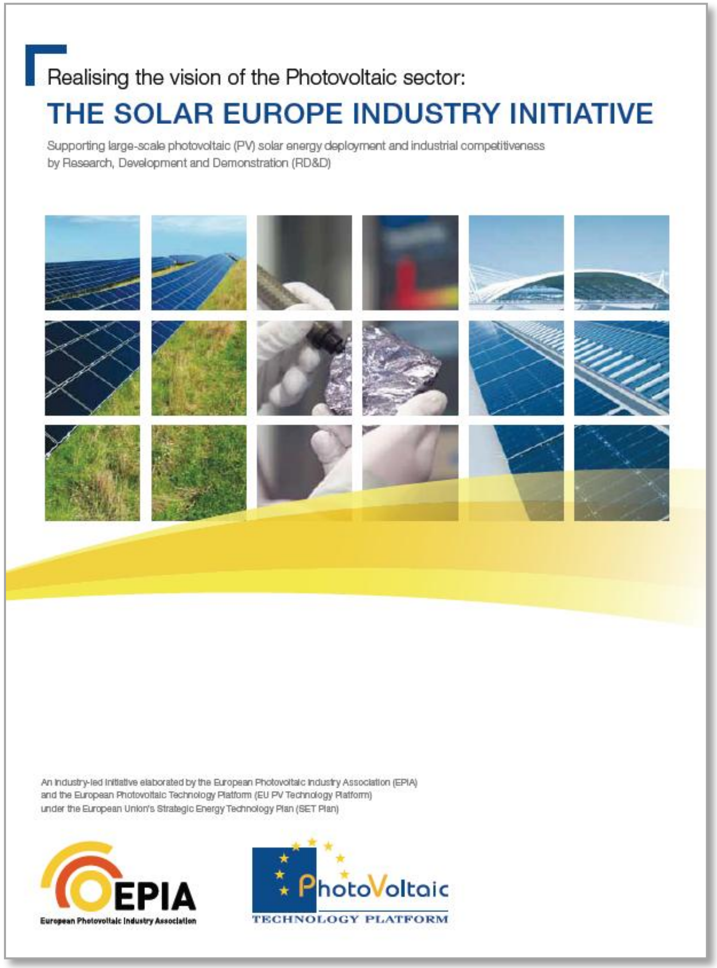
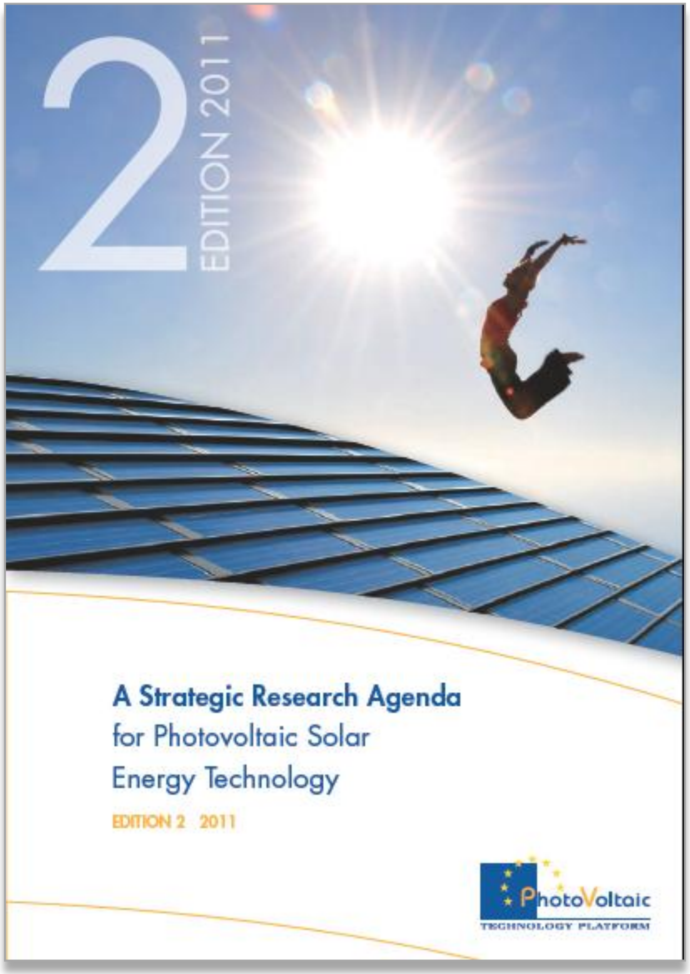
Outlook

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 <u>system integration</u> (selection)

High performance

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

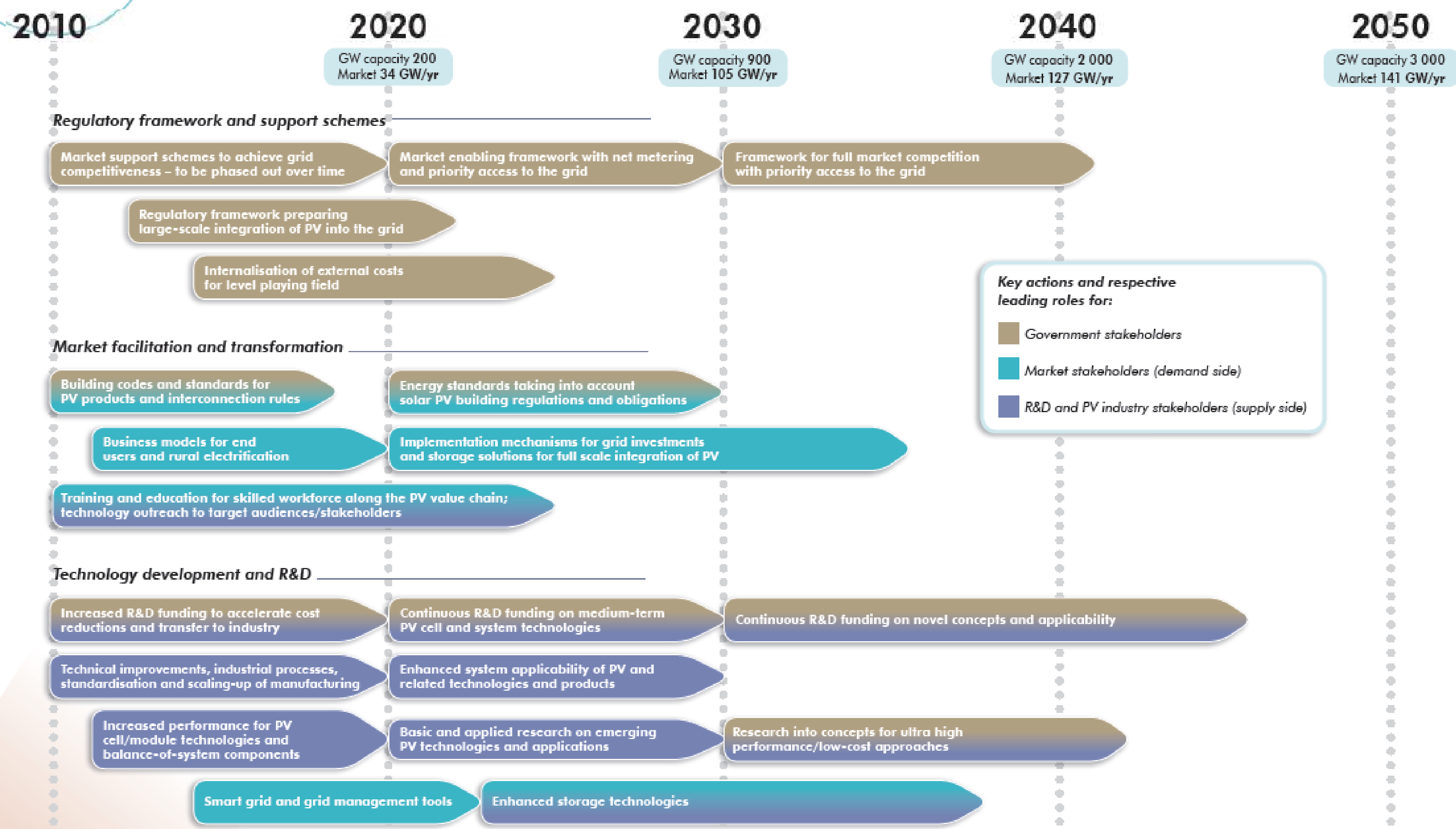
Low cost

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

Sustainability

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

Solar photovoltaic roadmap milestones



International Energy Agency
www.iea.org/roadmaps

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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)*

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Outlook

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


thank you for your attention!