Applied Solar Expertise

Globaler Stand und Weiterentwicklung von Markt und Technologie

Materials Valley, Hanau (Heraeus)

16th January, 2012

Dr. Winfried Hoffmann – ASE
Vice President EPIA
Consultant Applied Materials Solar
Member of Scientific Board of FhG-ISE and Supervisory Board of ISFH and Helmholtz

1. EPIA is the worlds biggest PV only oriented industrial association with currently over 240 members

2. The membership represents
   # the global PV industry
   # the complete value chain (material production, equipment manufacturing, component production, system integration, R&D institutes etc)
   # many national PV associations

EREC – European Renewable Energy Council

Umbrella organisation representing all RES sectors:

✓ **AEBIOM**	European Biomass Association
✓ **EBB**	European Biodiesel Board
✓ **EBIO**	European Bioethanol Industry Association
✓ **EGEC**	European Geothermal Energy Council
✓ **EPIA**	**European Photovoltaic Industry Association**
✓ **ESHA**	European Small Hydropower Association
✓ **ESTIF**	European Solar Thermal Industry Federation
✓ **EUBIA**	European Biomass Industry Association
✓ **EWEA**	European Wind Energy Association
✓ **EUREC Agency**	European Renewable Energy Research Centres Agency

Associate members:

✓ **EU-OEA**	European Ocean Energy Association
✓ **EREF**	European Renewable Energy Federation
✓ **ESTELA**	European Solar Thermal Electricity Association

Representation of European RES industry, trade & research

Content

Some prejudices about Renewables and PV solar electricity

- **PV is a fascinating but too expensive technology!**
- **PV needs too much support compared to what it delivers!**
- **PV is fluctuating daily and seasonally!**
- **PV is difficult to integrate into the grid network!**
- **… and the sun is not shining enough in Northern countries like Germany!**
- **Renewables can never deliver 100% of growing global energy needs!**

Source:

Content

Some prejudices about PV solar electricity

- PV is a fascinating but too expensive technology!
- PV needs too much support compared to what it delivers!
- PV is fluctuating daily and seasonally!
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- … and the sun is not shining enough in Northern countries like Germany!
- Renewables can never deliver 100% of growing global energy needs!

Source:

Content

- **PV is a fascinating but too expensive technology!**
  … quickly decreasing price, today‘s cost ~10-20 €ct/kWh, half latest by 2020
- **PV needs too much support compared to what it delivers!**
  … even in Germany the NPV for the cumulative support is positive
- **PV is fluctuating daily and seasonally!**
  … but adds perfectly to the afternoon peak demand in the summer season
- **PV is difficult to integrate into the grid network!**
  … but contributes very well to the anyway needed smart grids in the LV grid
- **Renewables can never deliver 100% of growing global energy needs!**
  ...technology supports energy efficiency and RE will be the cheapest!

Source:

PV Solar – serving a Multitude of Customer Needs

on-grid	off-grid	consumer	high efficiency
			
€/kWh	€/hr light	W/m²	g/W
			
€/m² / aesthetics	€/W	flexibility	W/mm²

Source: Fraunhofer ISE

Competitiveness

Between Electricity Generation Cost PV and Electricity Price

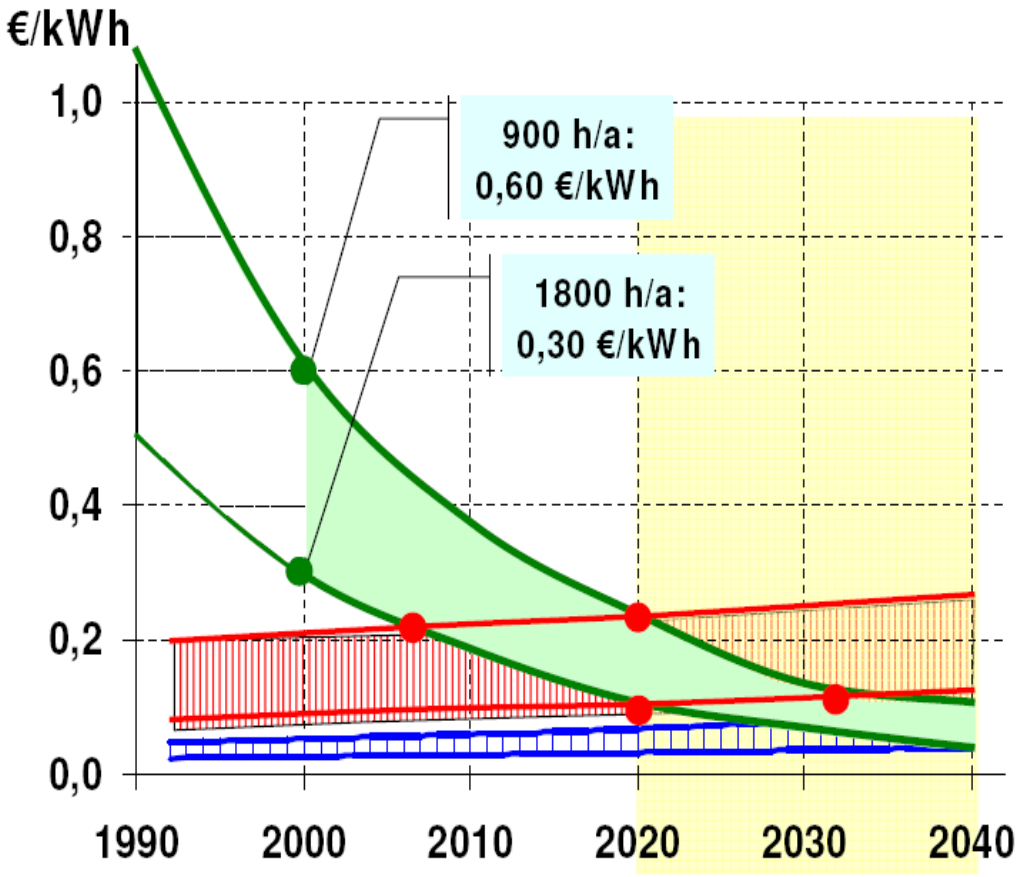
… only one „mistake“ in 1999:

- PV LCOE will decrease quicker after 2010 due to higher growth!
- Conventional electricity prices will go quicker up!

Photovoltaics

Retail prices private and small business

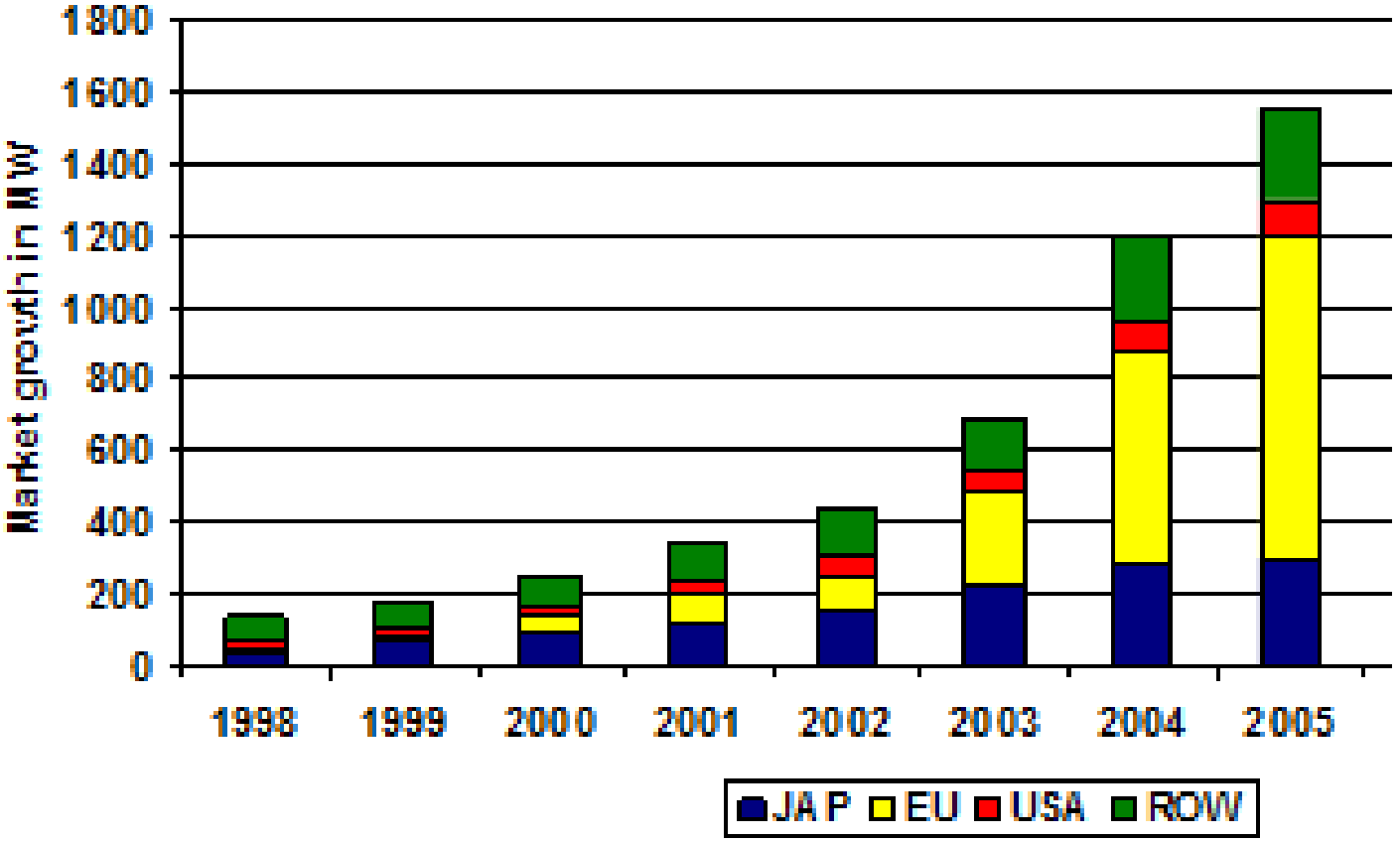
Large power consuming industries



market support programs necessary:

Ref: W. Hoffmann personal estimates, 1999

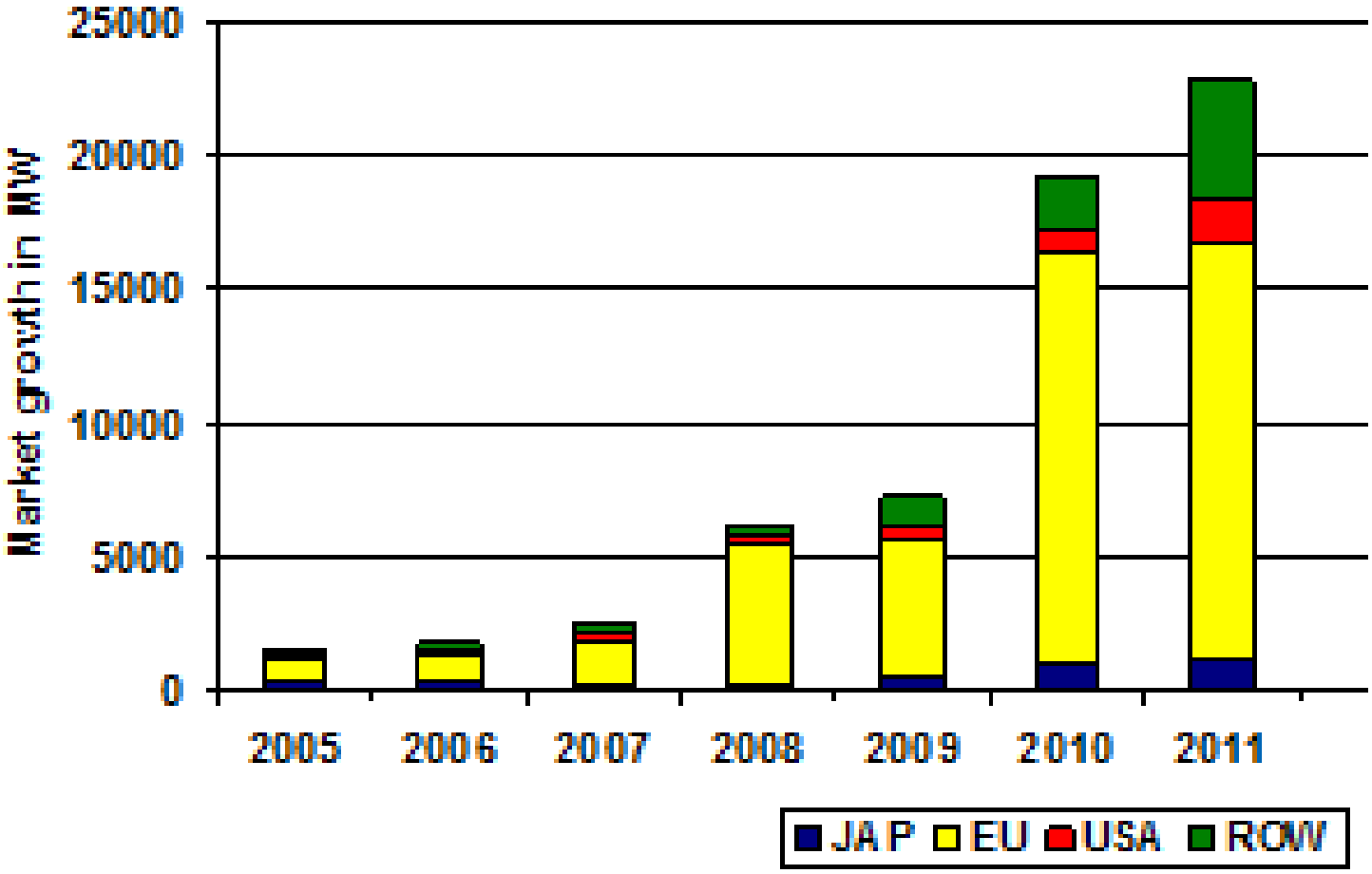
Global PV Market Growth 1998 - 2005



Top 10 production companies 2000

Company	% share	MW shipped	Company	% share	MW shipped
Kyocera (J)	15	42	Photowatt (F)	5	13
BP Solar (US)	15	42	Sanyo (J)	4	11
Sharp (J)	15	42	Isofoton (Spain)	3	8
Siemens Solar (Ger/US)	11	31	Mitsubishi (J)	2	6
Astro Power (US)	6	17	other	19	55
ASE (Ger/US)	5	13	total	100	280

Global PV Market Growth 2005-2011



The top 10 in 2009 and 2010 (MW) worldwide

#	2009		2010	
1	Germany	3.806	Germany	7.700
2	Italy	723	Italy	2.300
3	Japan	483	Czech Rep	1.360
4	USA	477	Japan	990
5	Czech Rep	398	USA	900
6	Belgium	285	France	719
7	China	~200	Spain	367
8	France	185	Belgium	361
9	South Korea	167	Australia	320
10	Australia	79	China	~400

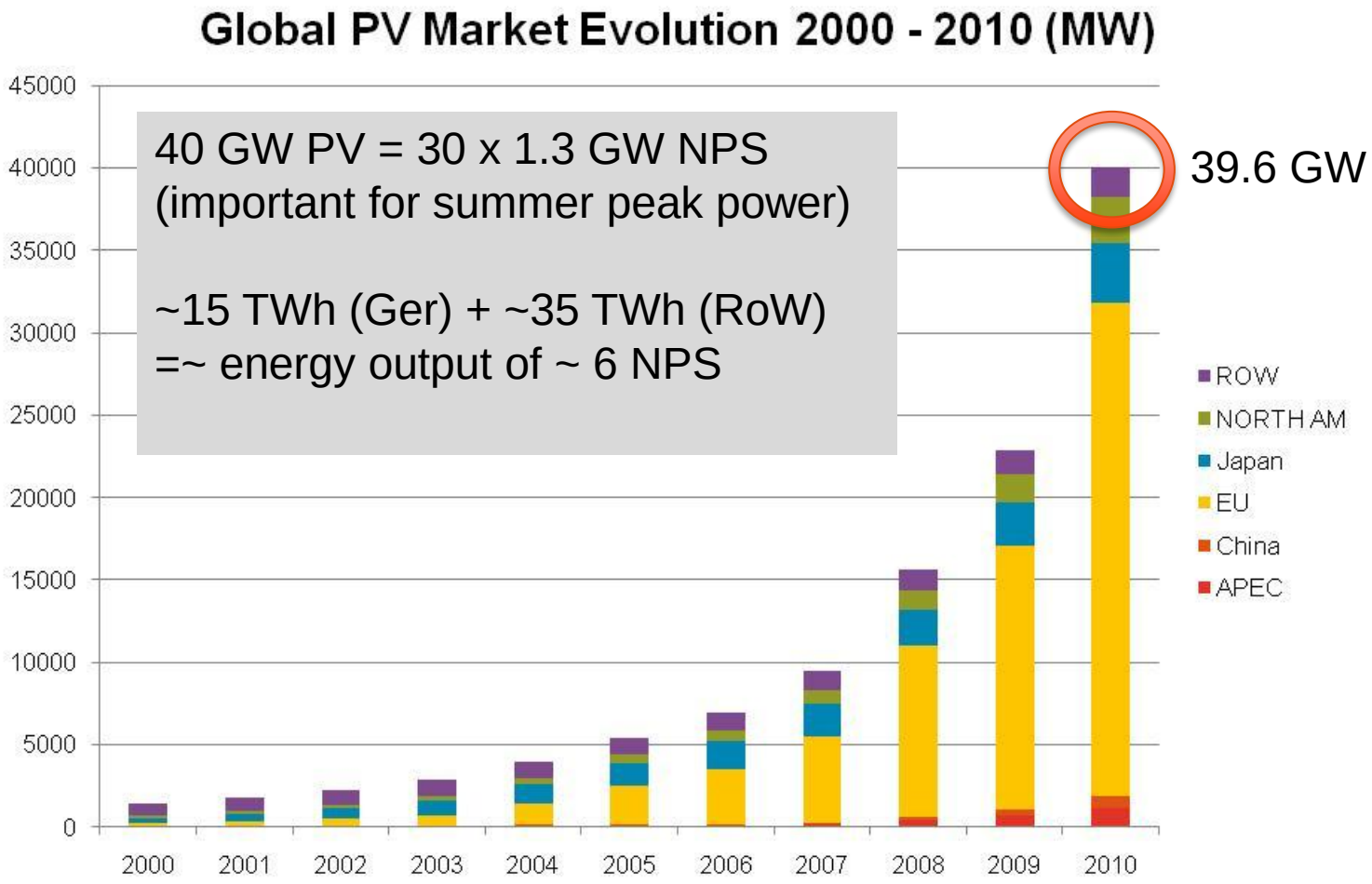
Top 10 production companies 2010

Company	% share	MW shipped	Company	% share	MW shipped
Suntech (China)	7.9	1572	Q-Cells (Germany)	4.5	907
JA Solar (China)	7.3	1464	Gintech (Taiwan)	4.2	827
First Solar (US)	7.1	1411	Sharp (Japan)	3.9	774
Yingli Solar (China)	5.3	1062	Canadian Solar (Canada/China)	2.9	588
Trina Solar (China)	5.3	1057	Others	~47	~9,400
Motech Solar (Taiwan)	4.6	924	Total	100	~20,000

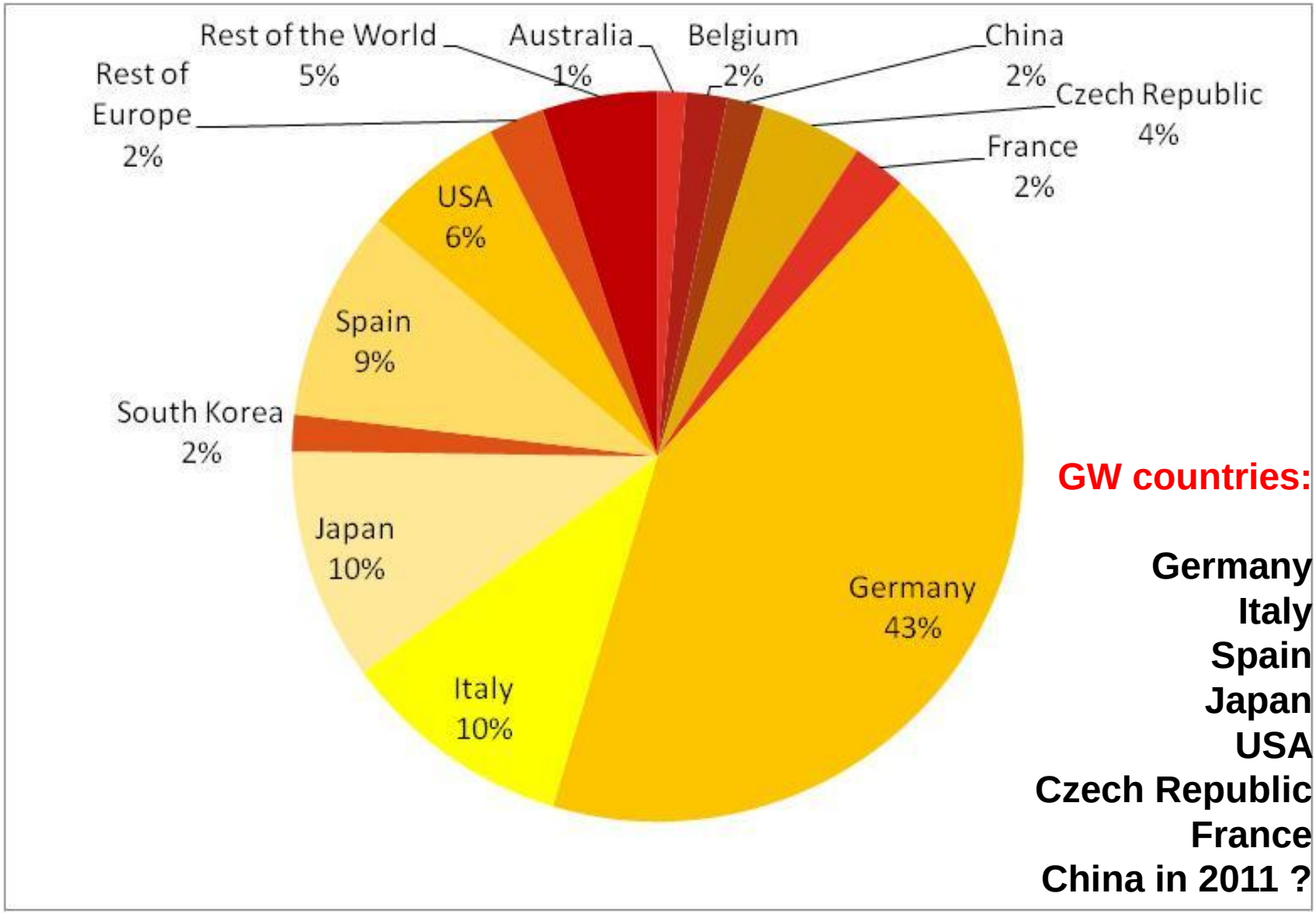
Market allocation versus regional production of PV modules

Source: EPIA, Navigant Consulting (Paula Mints)

Cumulated installed capacity until 2010



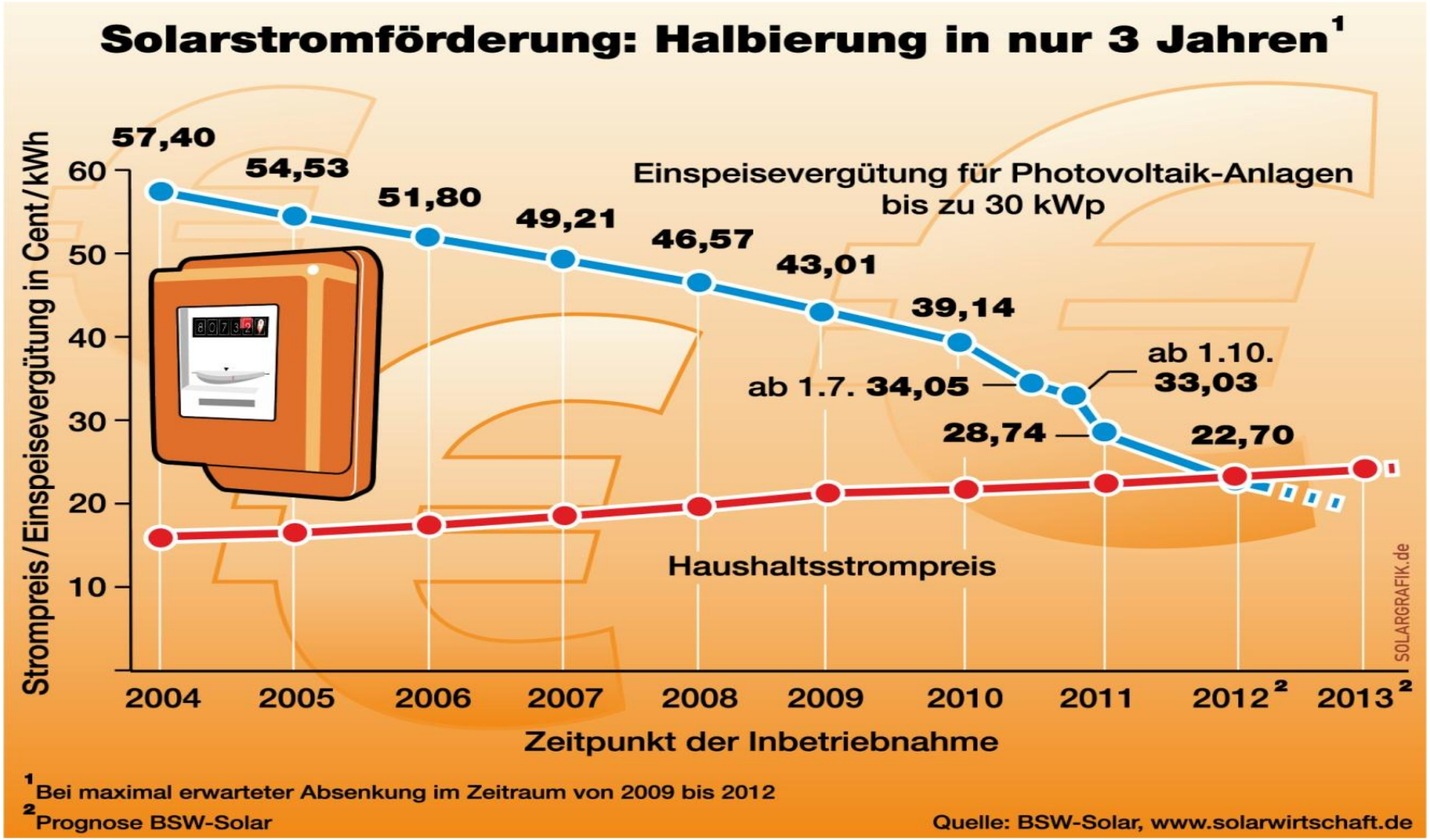
Cumulative installed capacity 2010



GW countries:

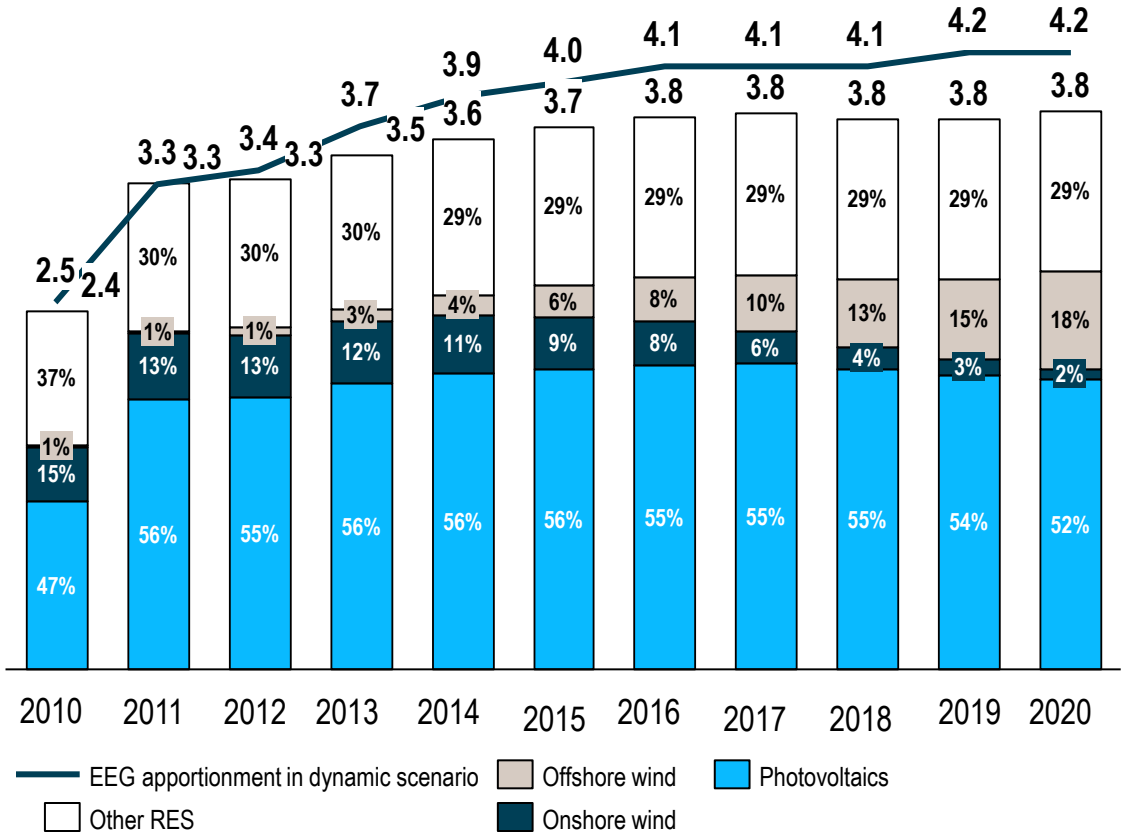
Germany
Italy
Spain
Japan
USA
Czech Republic
France
China in 2011 ?

Development of Feed-in tariff in Germany



Implications for apportionment: Short term increase in apportionment – Medium term projection at 4 cents, thereof 2 cents from PV

Development of EEG apportionment in NAP scenario [ct/kWh]

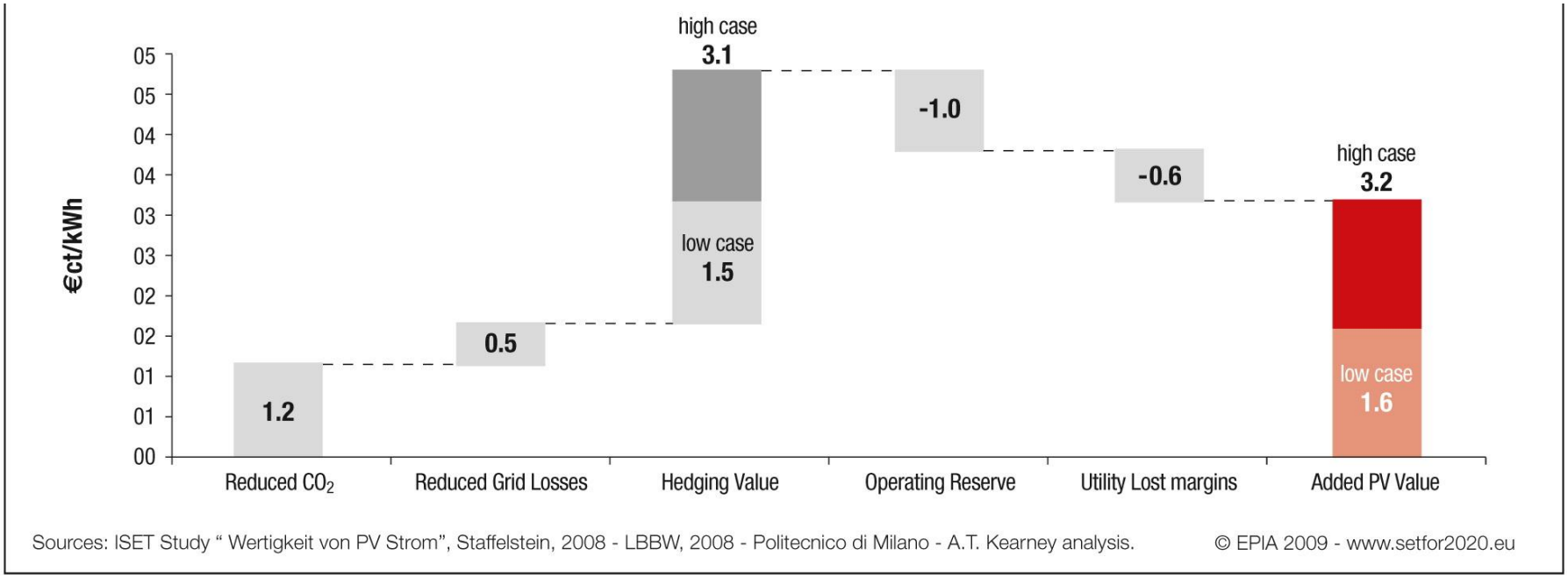


Comments

- In the short-run remuneration driven by significant expansion in 2010 and 2011 – high costs make these years decisive
- Degression and shift to 3 GW path brings about much lower growth rate after 2012
- Key factors are direct consumption and green electricity privilege
- Grid operators expect higher expansion figures, resulting in higher apportionment
- In NAP scenario, differential costs decrease as of 2016, as revenue increase from day-ahead-marketing exceeds increase from remuneration

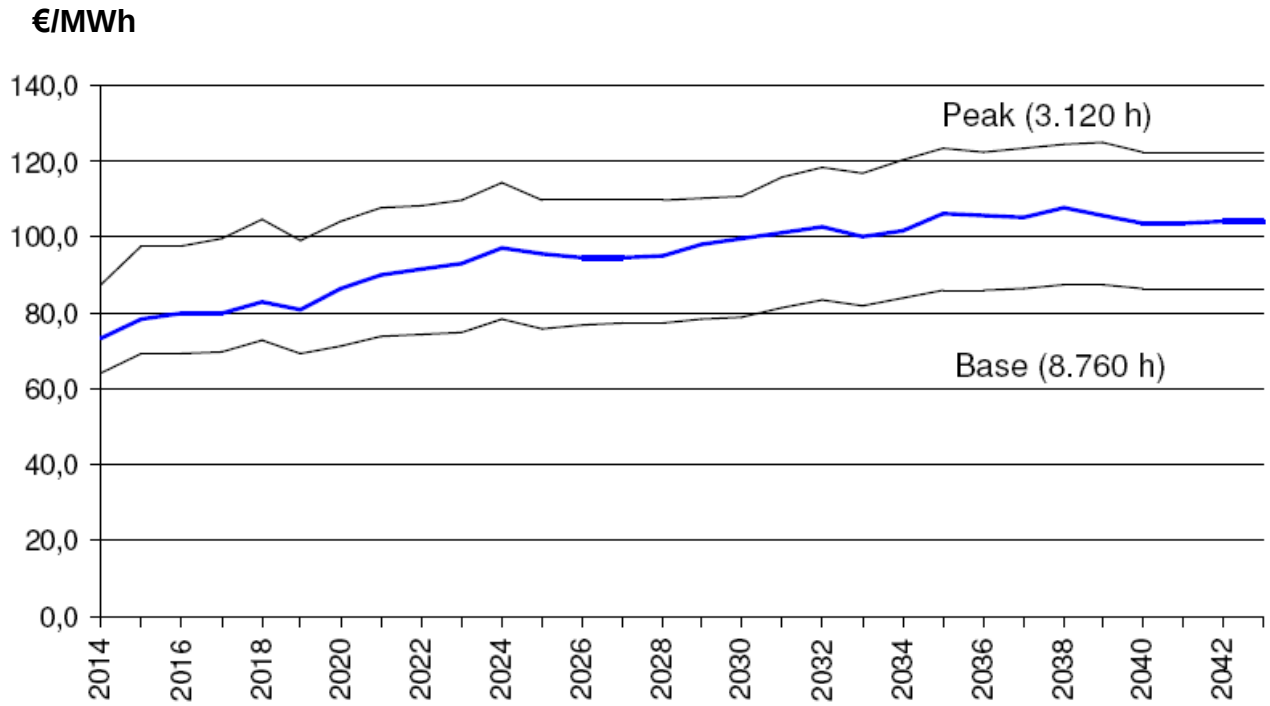
Source: Roland Berger; Prognos

Incremental value of a PV produced kWh compared with a gas fired power plant



Sources: ISET Study " Wertigkeit von PV Strom", Staffelstein, 2008 - LBBW, 2008 - Politecnico di Milano - A.T. Kearney analysis.

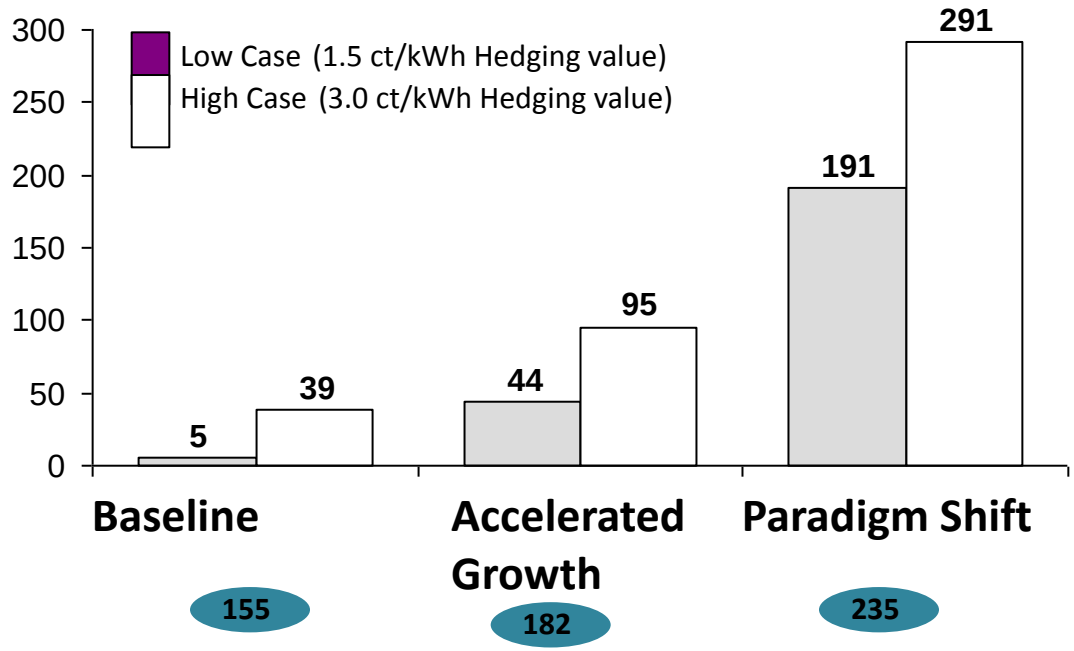
Projection of electricity market prices in €/MWh



Expected price increase in 20 years (2014-2034) from 90 to 120 Euro/MWh (corresponding to 1.5 €ct/kWh hedging value)

Ref.:SüdWestStrom, Marktstudie zur Strompreisentwicklung in Deutschland, Vorgehensweise und indikative Ergebnisse einer Berechnung, Mai 2008

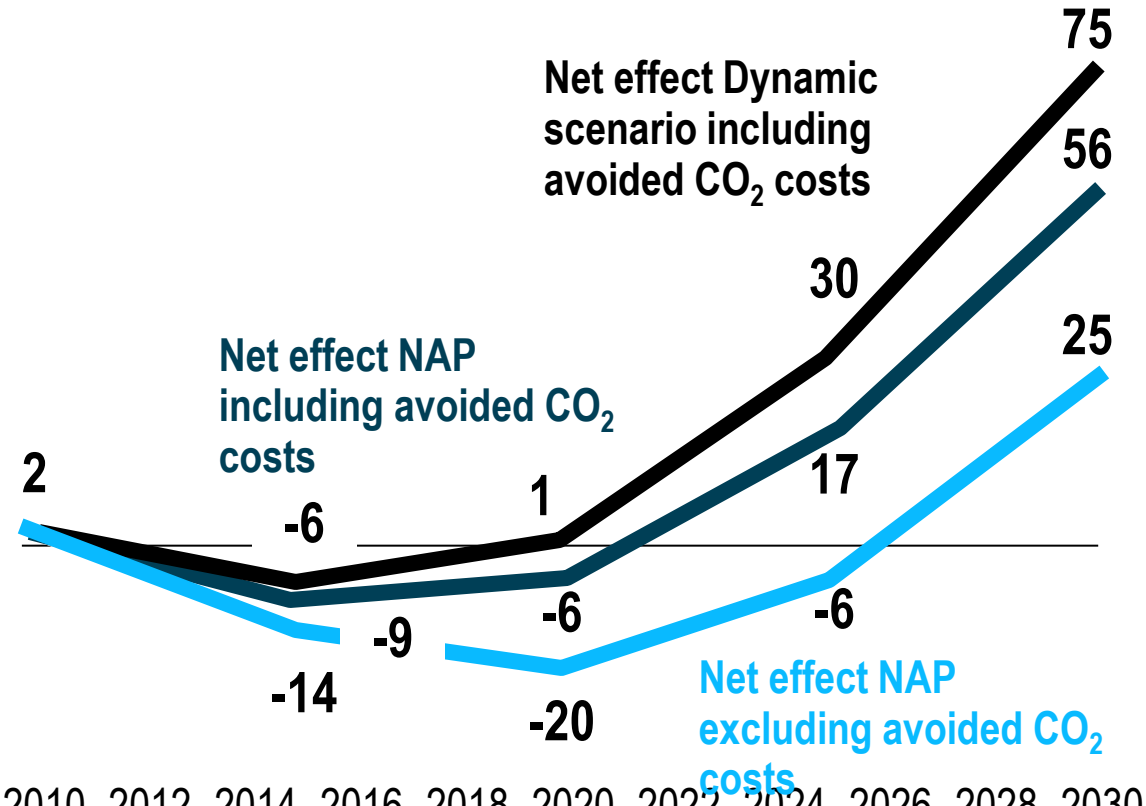
Net present benefit from PV deployment



€ billion FiT investment needed in absolute values

As of 2020, PV will make a sustained positive economic contribution – 2020-2025 balance will be stable

Sustained economic net balance of PV technology [actual, bn EUR][1)]



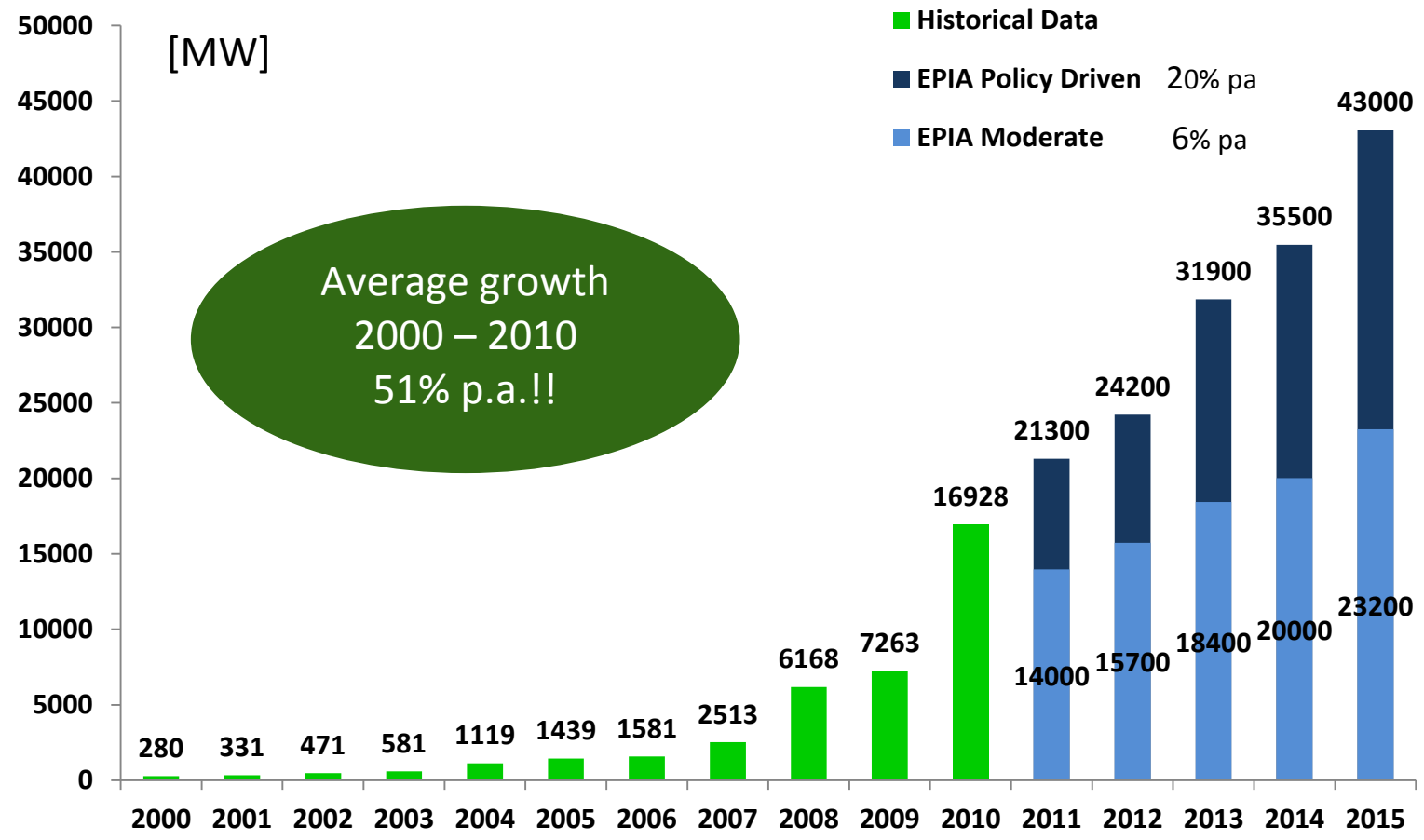
1) NAP scenario, discounted values, low oil price trajectory

Conclusion:

PV pays off for Germany in the long run

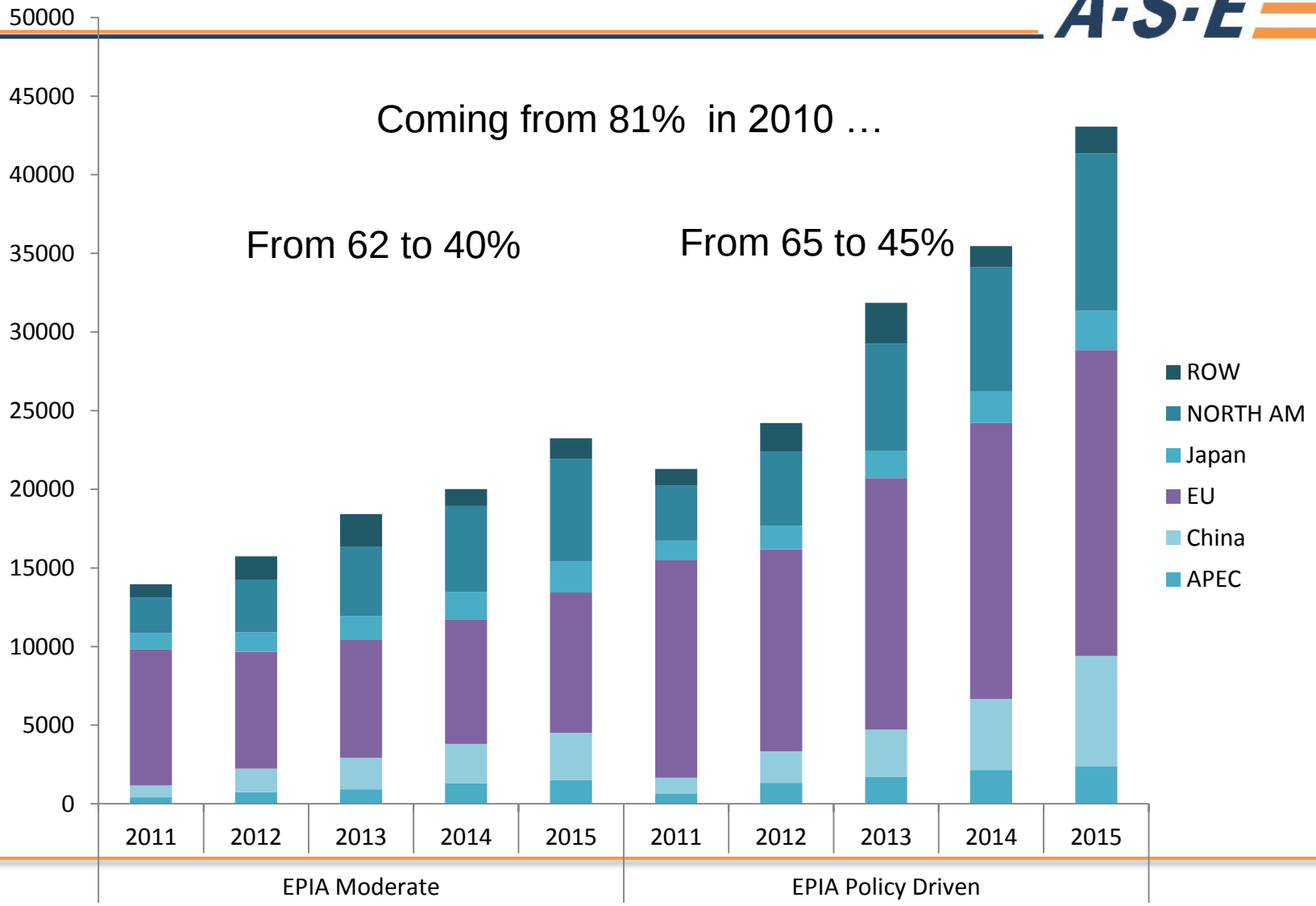
Source: Prognos; Roland Berger

Historical and next 5 year PV market growth (bottom-up)

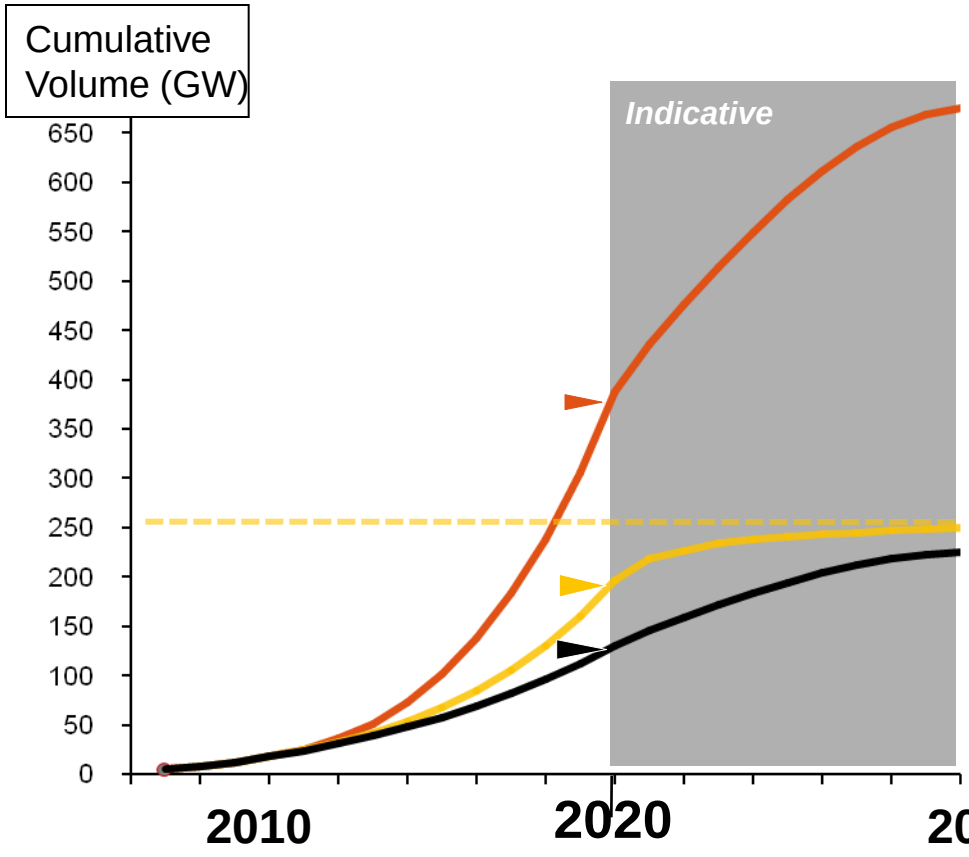


Source: EPIA market workshop, Paris, 2011

Share of EU vs World



SET For 2020 – PV penetration in EU - a top-down approach



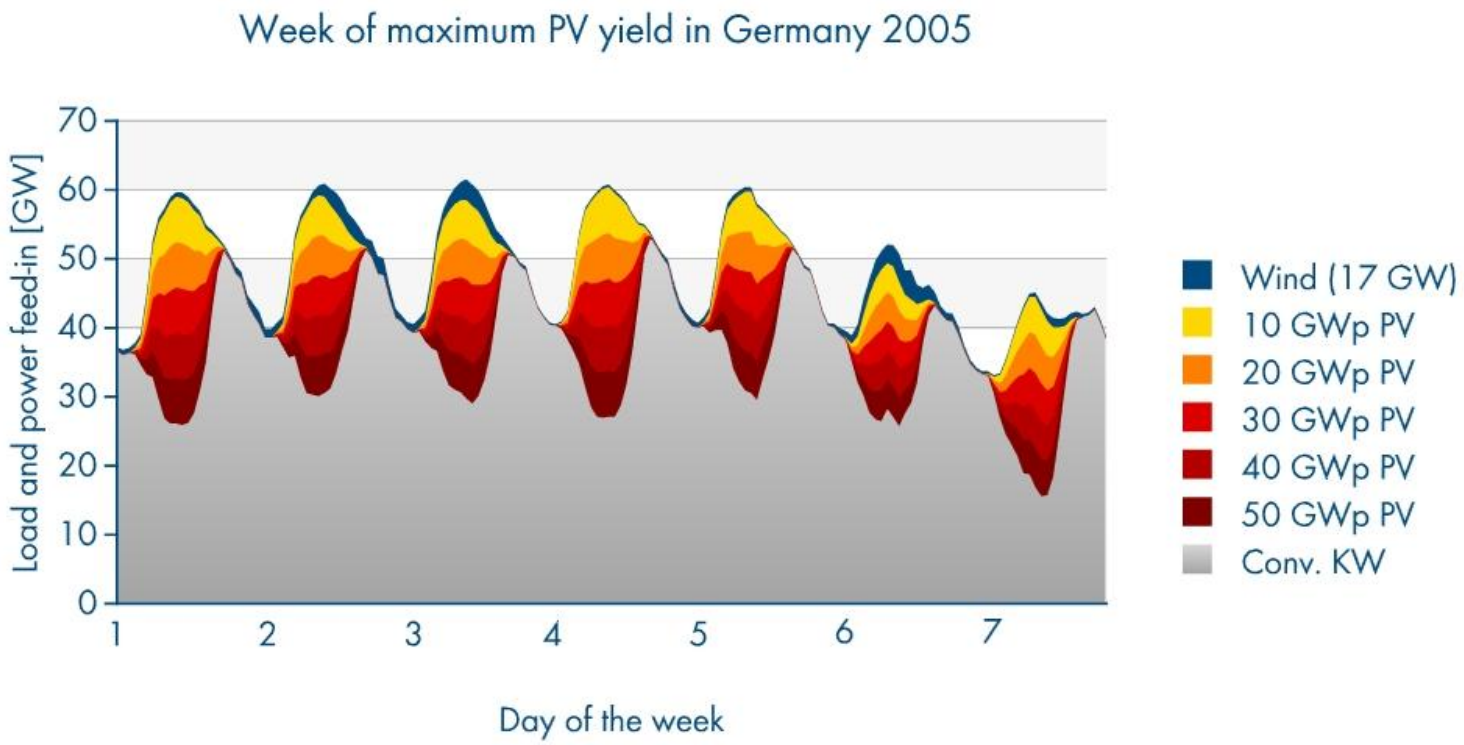
Share of e-Demand by 2020 in EU

Paradigm Shift Scenario: 12% (~ 400 GW)

Accelerated Scenario: 6% (~ 200 GW)

Baseline Scenario: 4% (~ 130 GW)

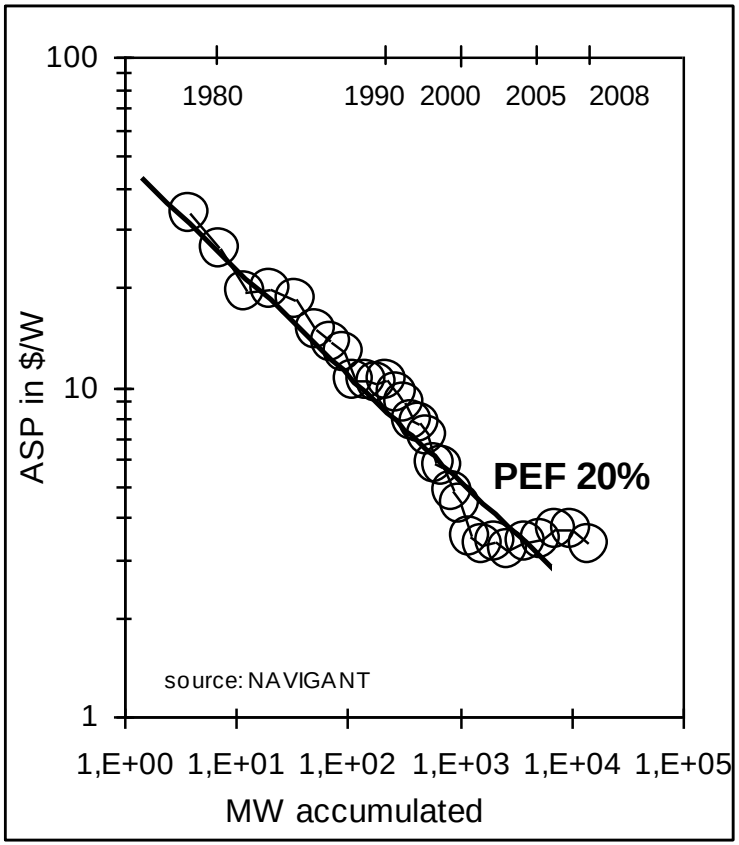
Electricity Load Curve in Germany and Impact of up to 50 GW PV



- PV reduces the afternoon peak!

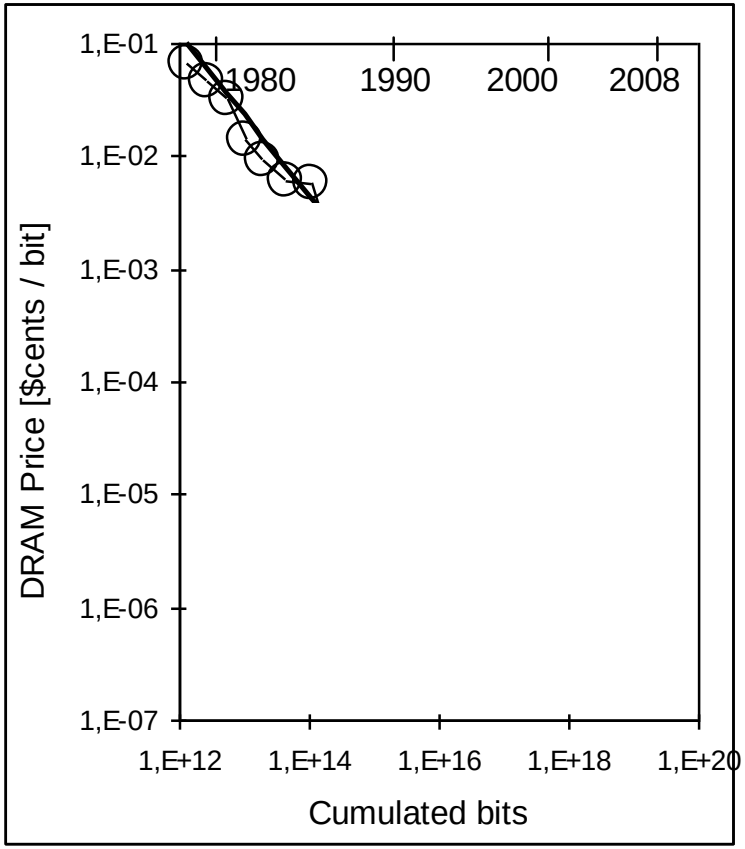
Photovoltaic Modules

Price Experience Curve

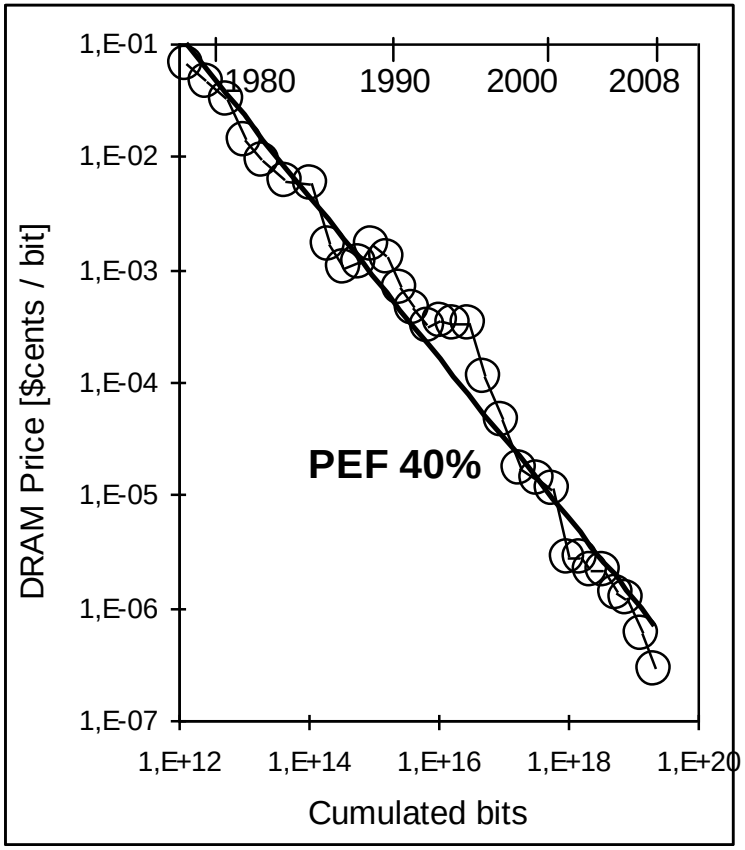


DRAM – Moore´s Law

Experience Curve



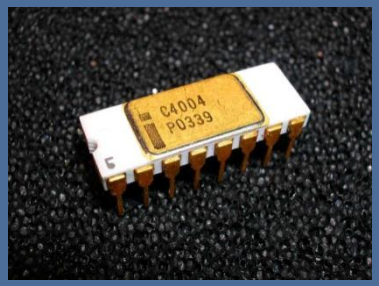
Experience Curve



Source: Applied Materials, Semiconductors Group, 2009

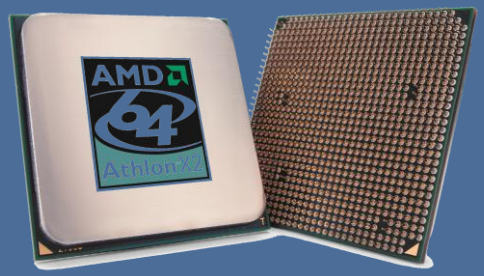
Semiconductor – Tremendous Development

1971

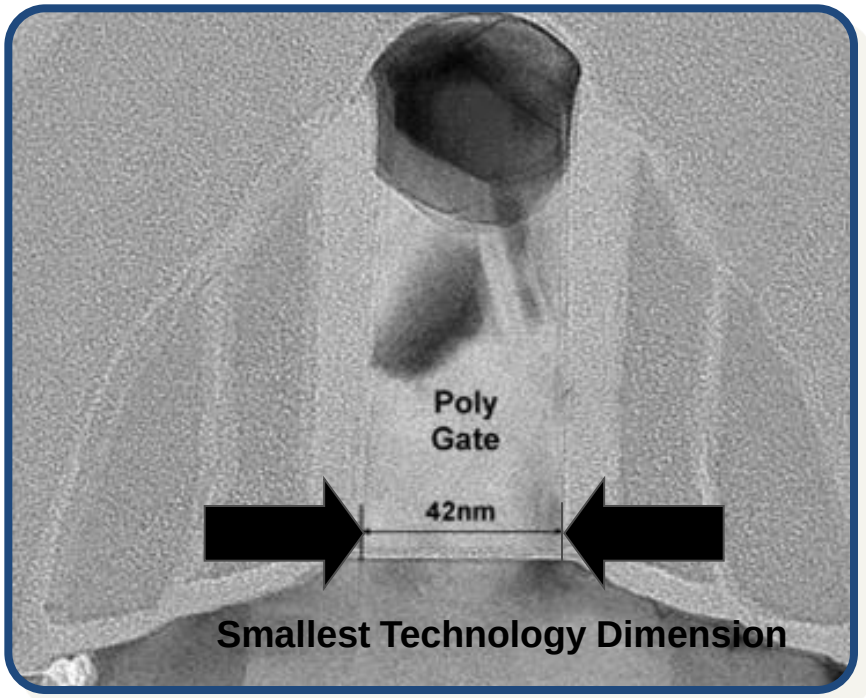


4 bit Microprocessor, Intel, 1971

Today



State-of the Art Microprocessor, AMD, since 2005

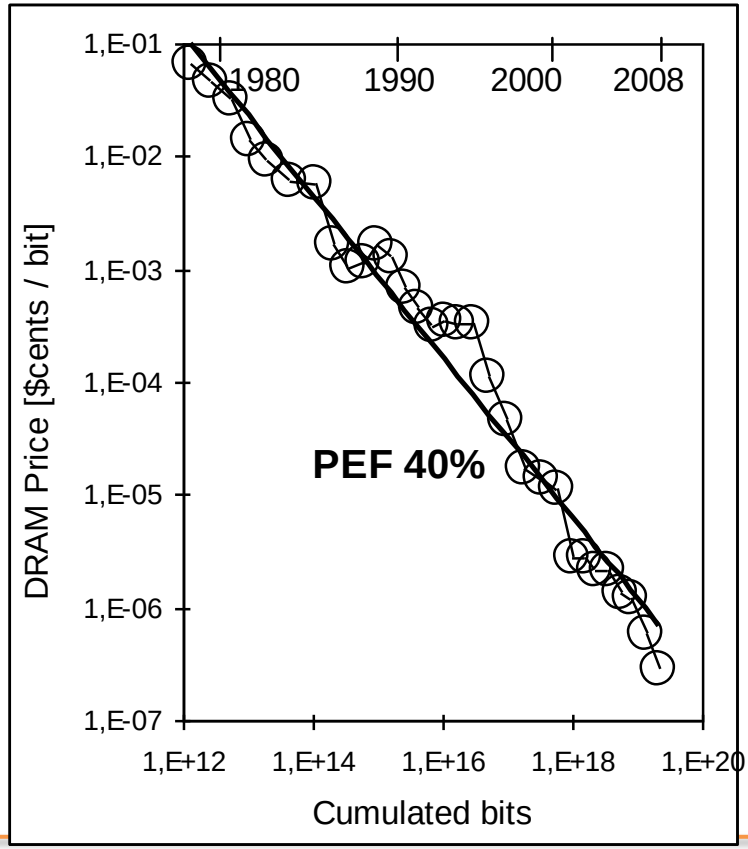


AMD PMOS transistor with physical gate length of 42nm

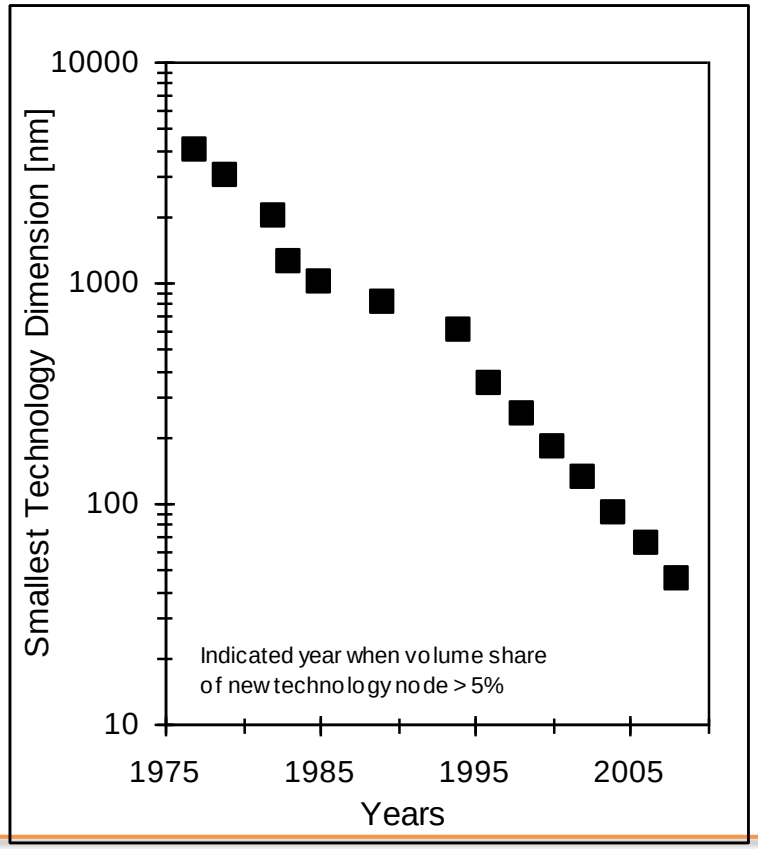
Source: Semiconductor Insights Inc.

DRAM – Moore´s Law

Experience Curve



Driven by Technology

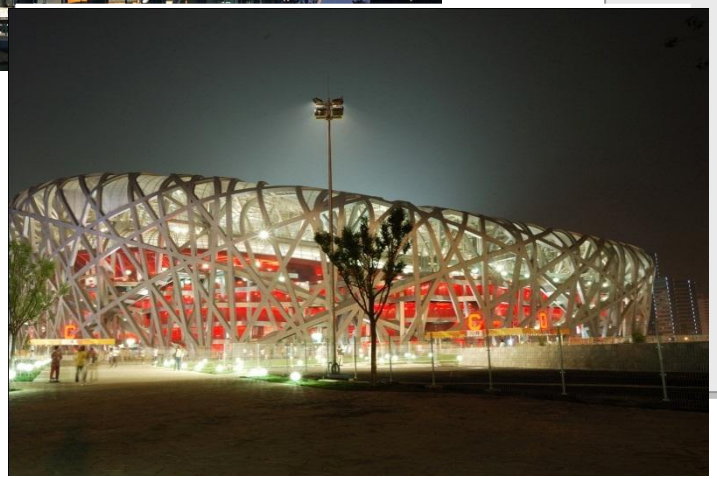


Source: Applied Materials, Semiconductors Group, 2009

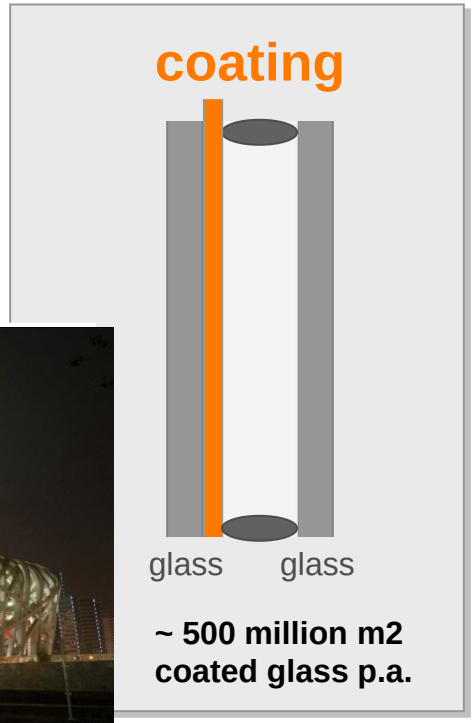
Architectural Glass

Atlantic Hotel Sail City,
Bremerhaven, Germany

Baltimore Visitor Center
Baltimore, MD USA



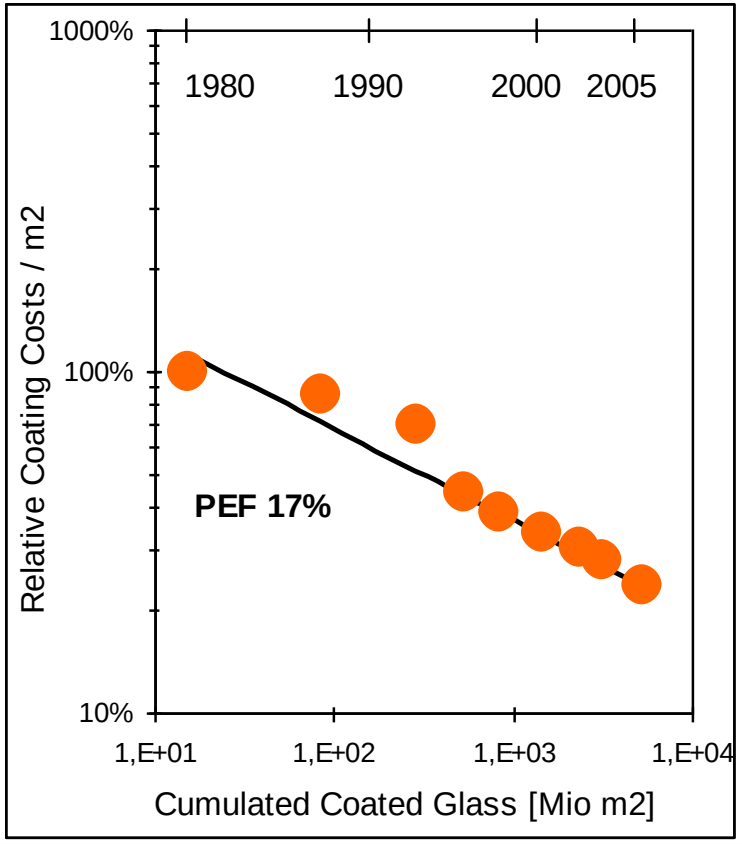
Bird's Nest Stadium,
Beijing PRC



~ 500 million m2 coated glass p.a.

Glass Coating

Price Experience Curve



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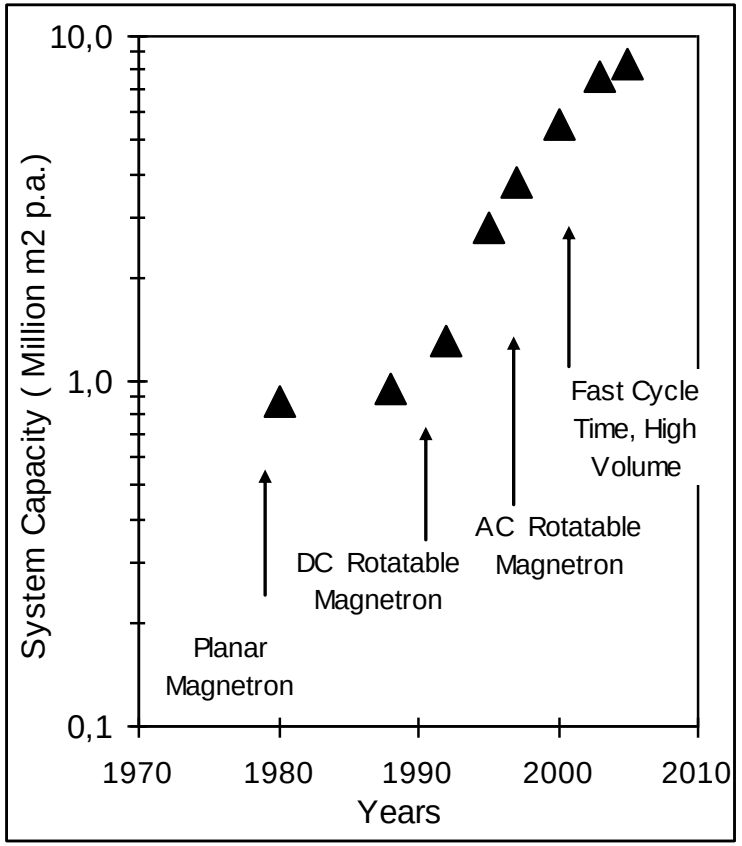
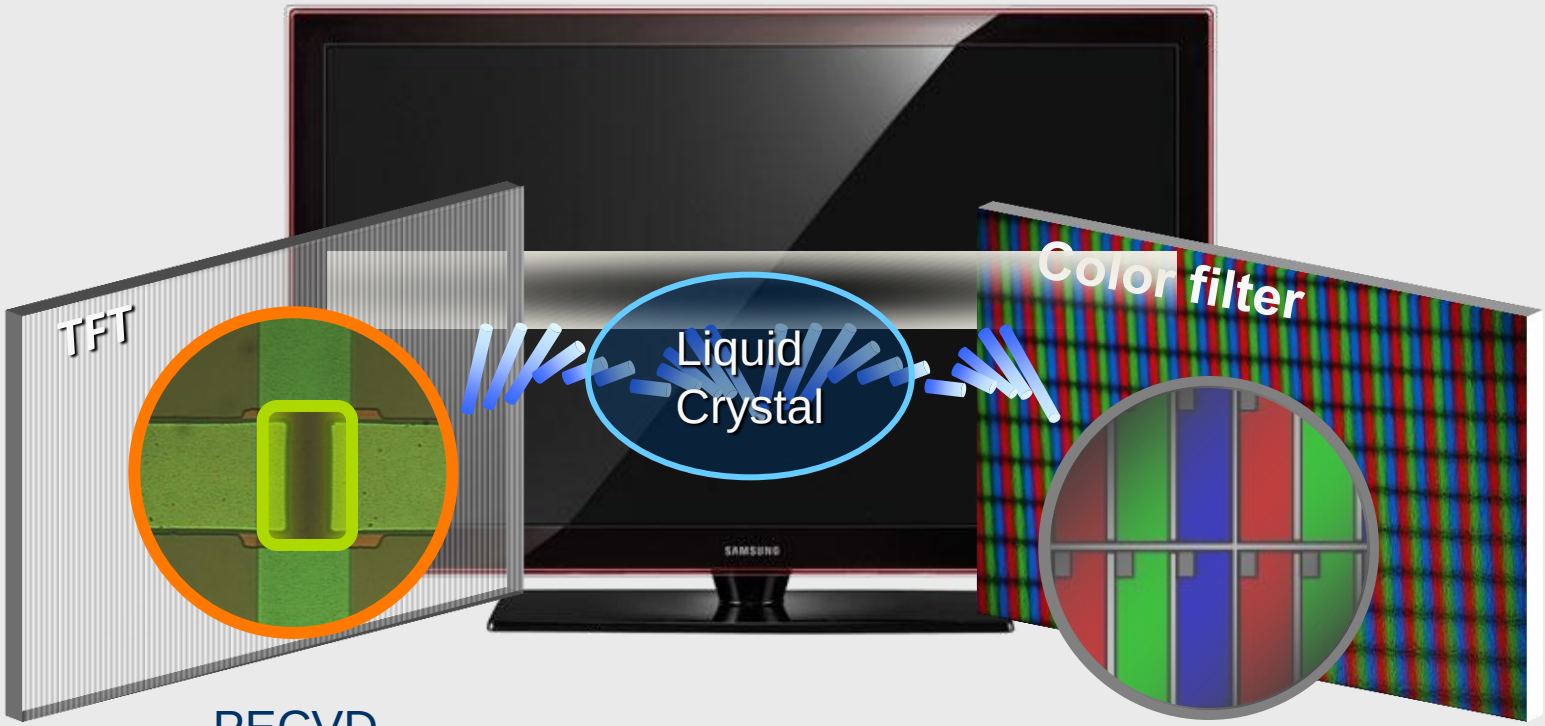


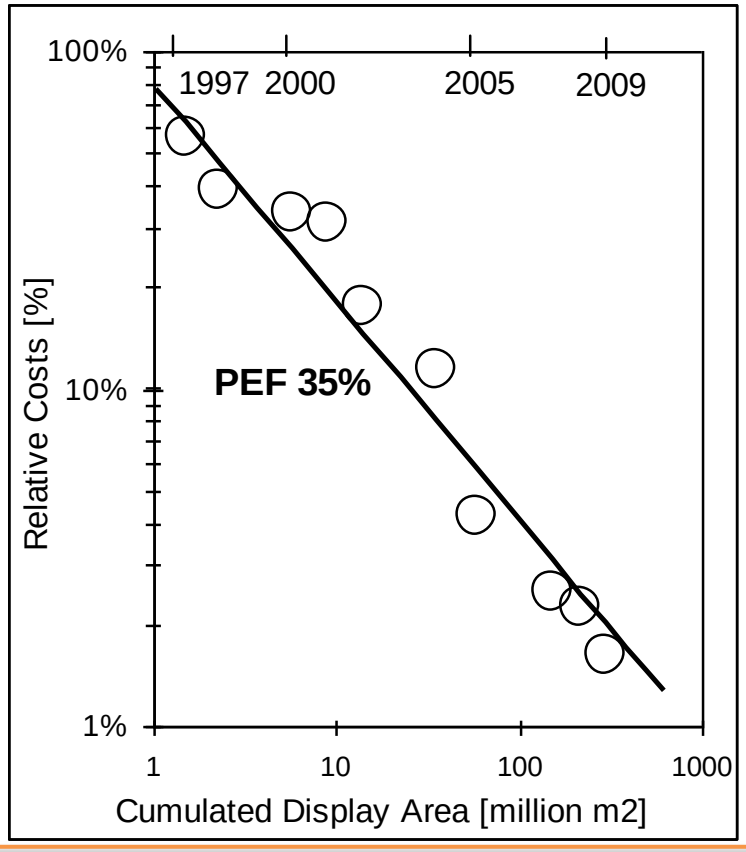
Source: Applied Materials, Energy and Environmental Solutions, 2009

Display: TFT-LCD Panel Technology



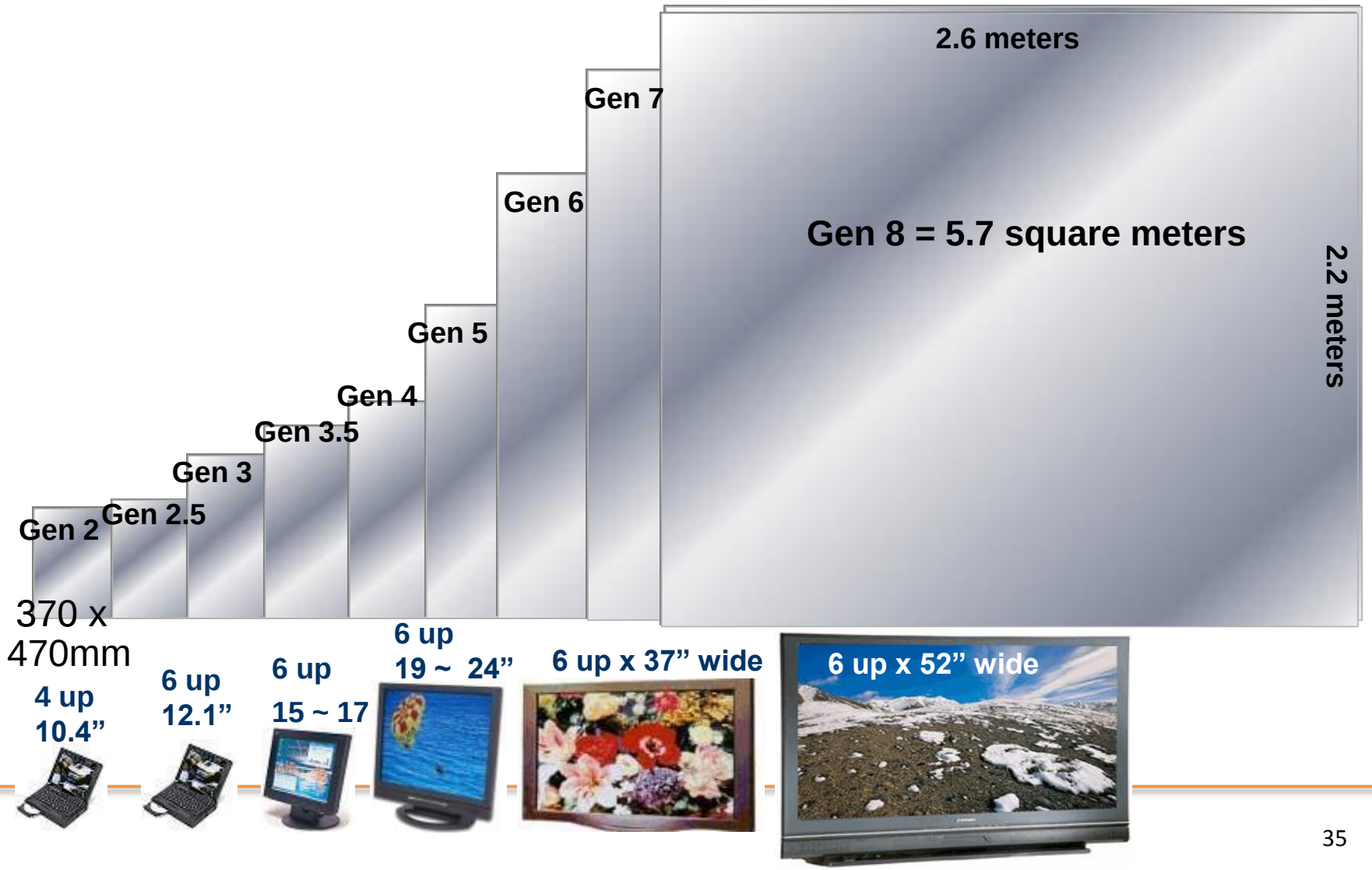
Display – Experience Curve

Experience Curve



Source: Applied Materials, Display Group, 2009

Substrate Size Expansion in LCD



TFT-LCD Panel Technology

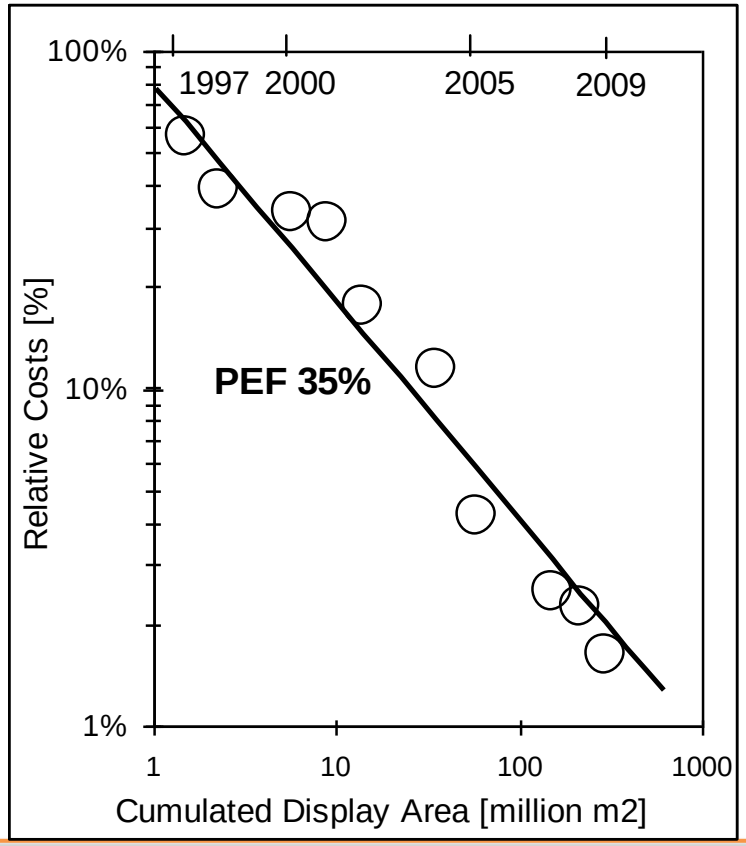
TFT PECVD

Color Filter PVD

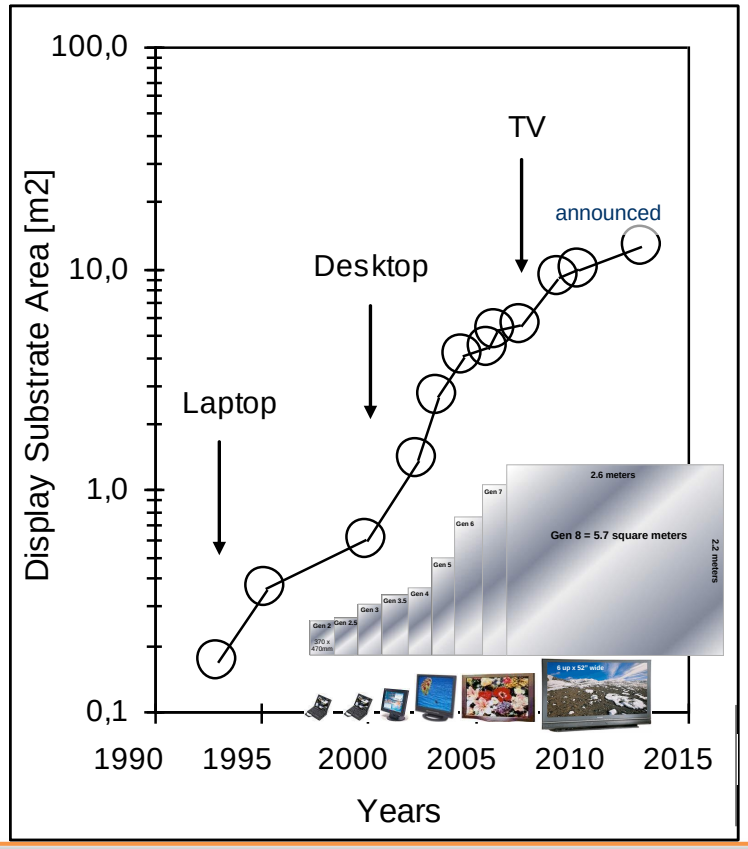
Source: Applied Materials, Display Group, 2009

Display

Experience Curve

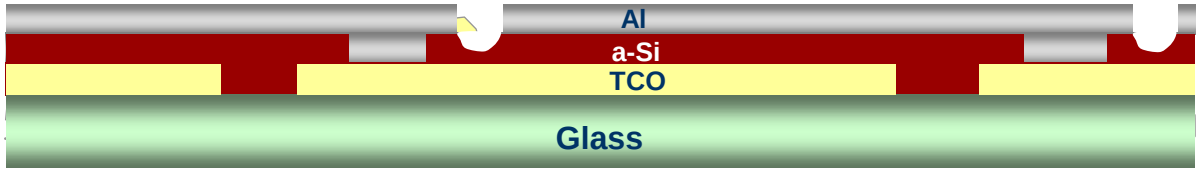


Driven by Technology



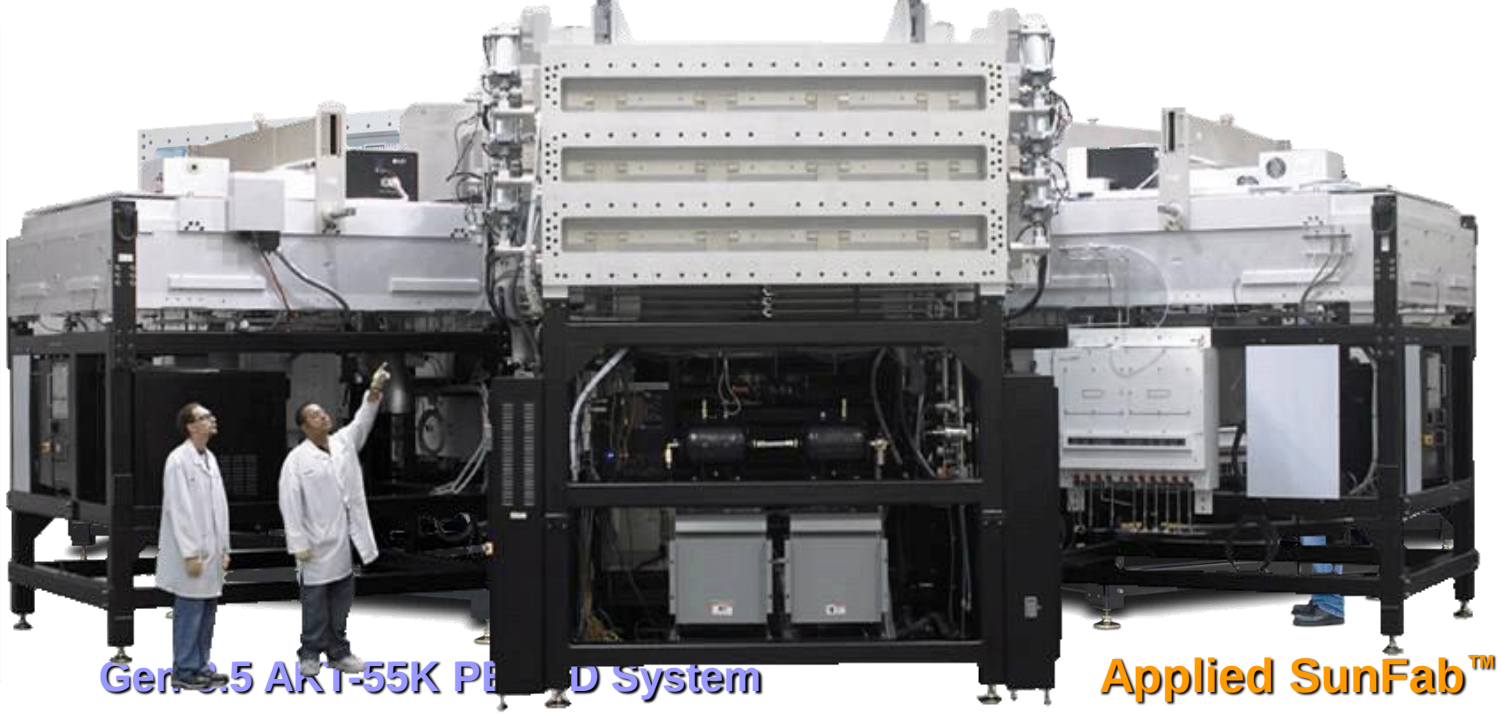
Source: Applied Materials, Display Group, 2009

From Display to Solar



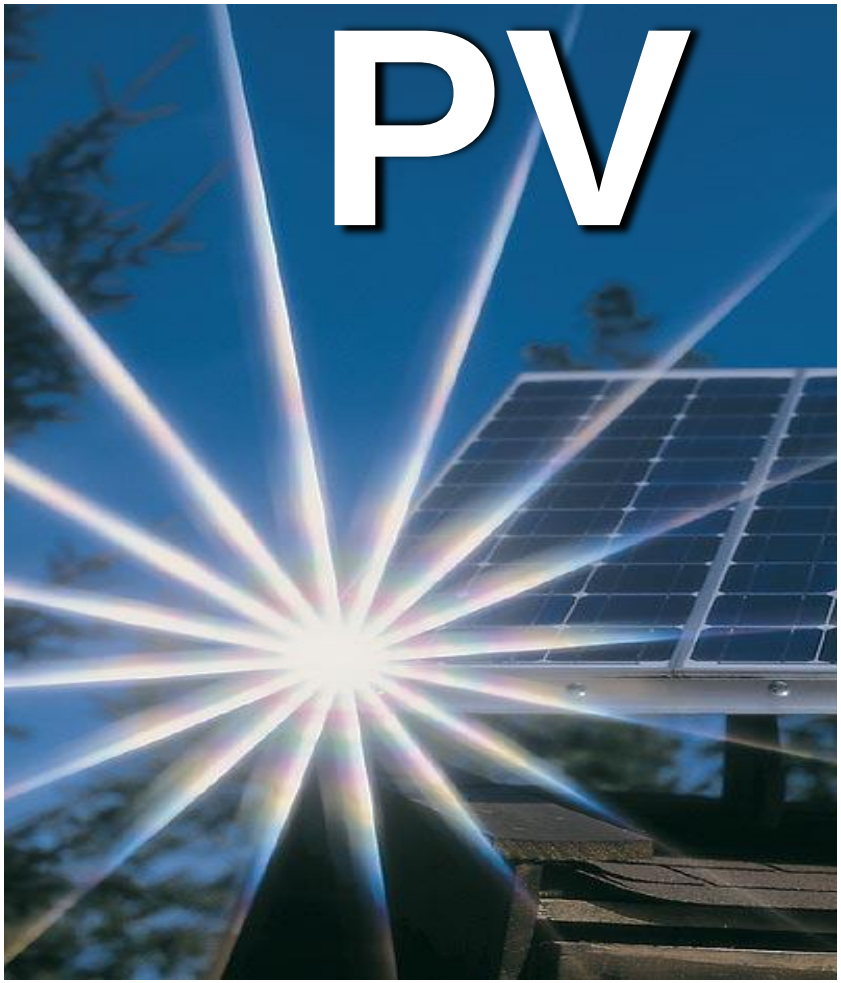
Thin Film Transistor (TFT) Structure

Thin Film Solar Structure (Single Junction)



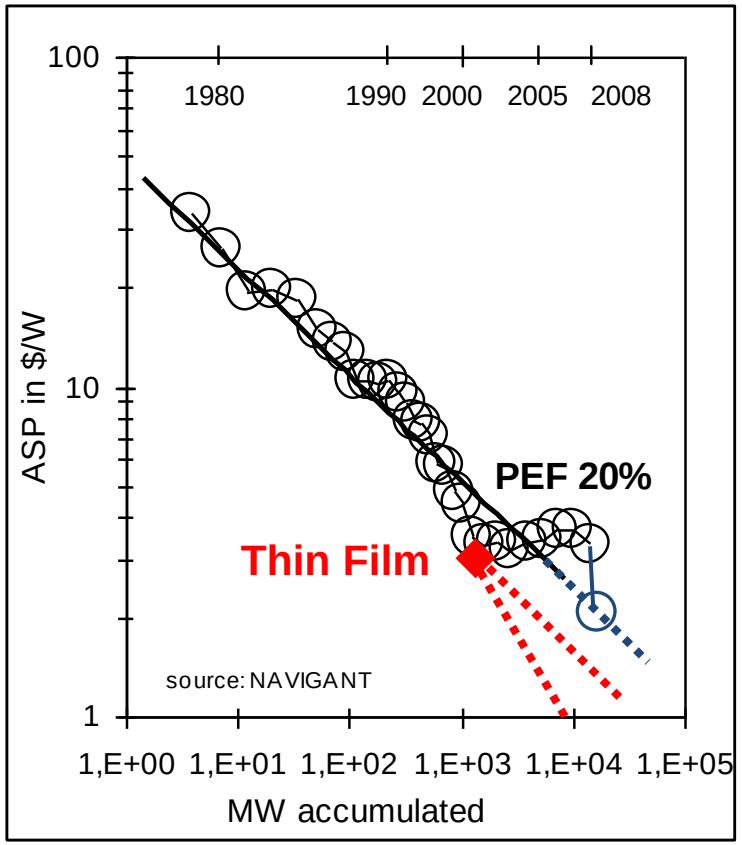
Gen 8.5 AKT-55K PECVD System

Applied SunFab™
Gen 8.5 PECVD System


PV

Photovoltaic

Price Experience Curve



Driven by Technology

- **Wafer thickness**
  0,7mm → 0,15mm
- **Kerf loss**
  0,5mm → 0,10mm
- **Efficiency**
  8% → 22%
- **Automation**
  Industrial manufacturing
- **Economy of scale**
  0,1MW → 200MW

1. PEC for c-Si will continue

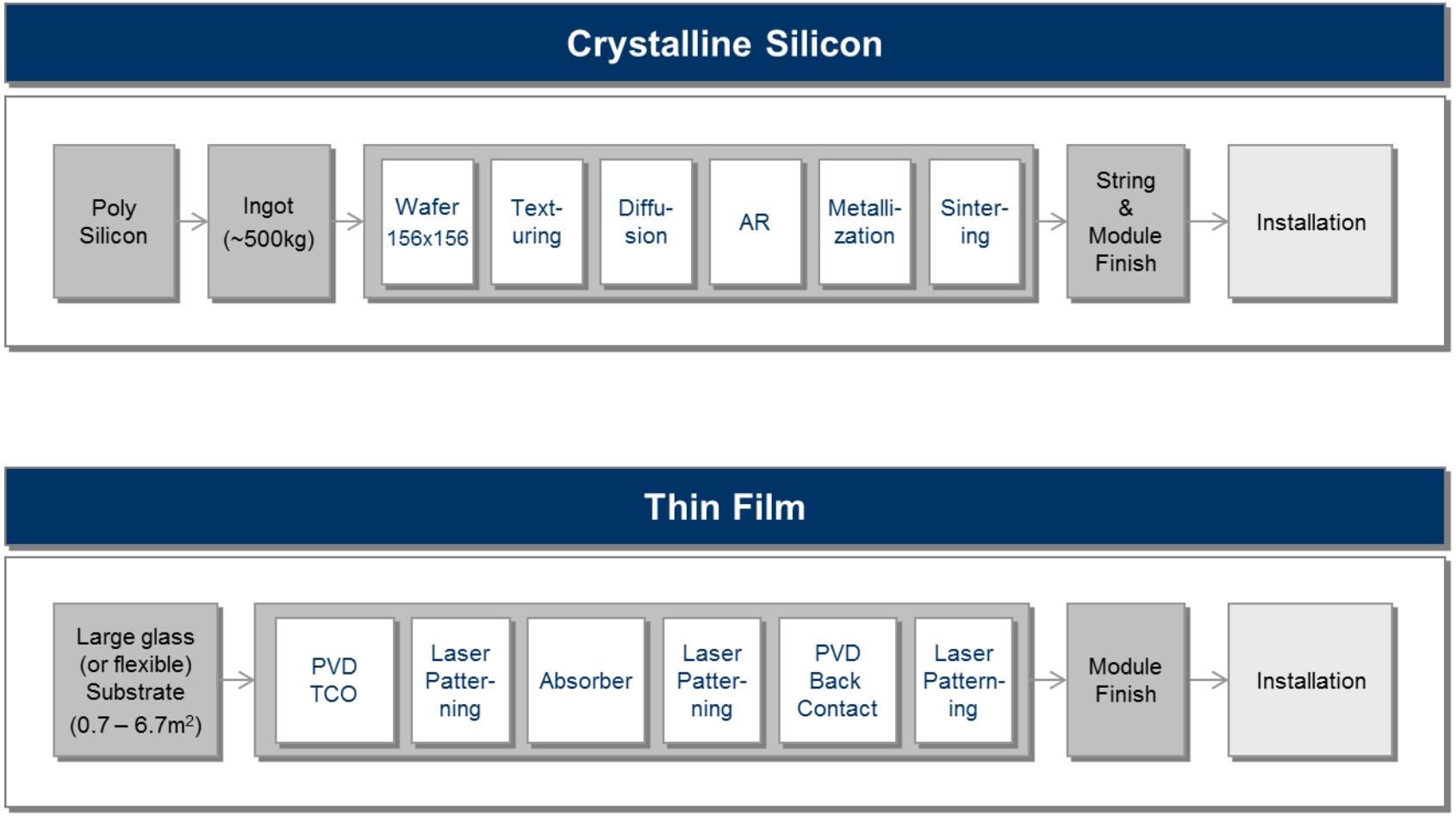
2. Reason for different PEC and PEF for Thin Film PV

3. Different growth rates for global PV installations as parameter

4. Different fraction of TF/c-Si as parameter

PEC = Price Experience Curve
PEF = Price Experience Factor

PV Value Chains

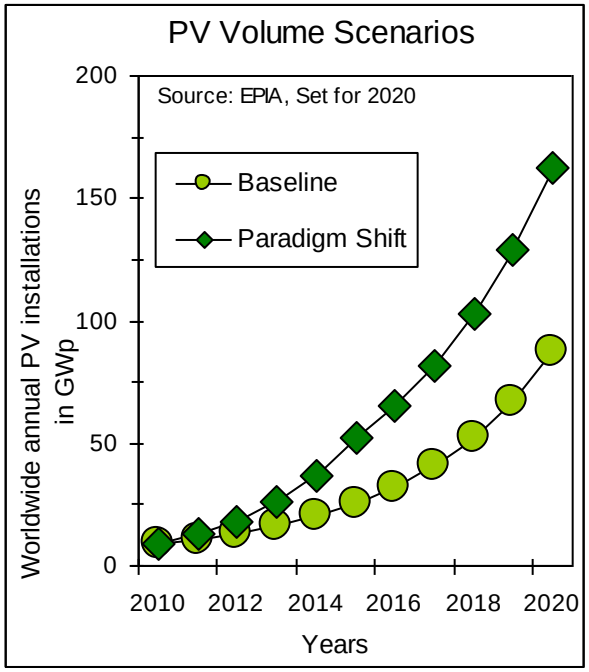


PV Future – Eight Cases

Evaluation Cases

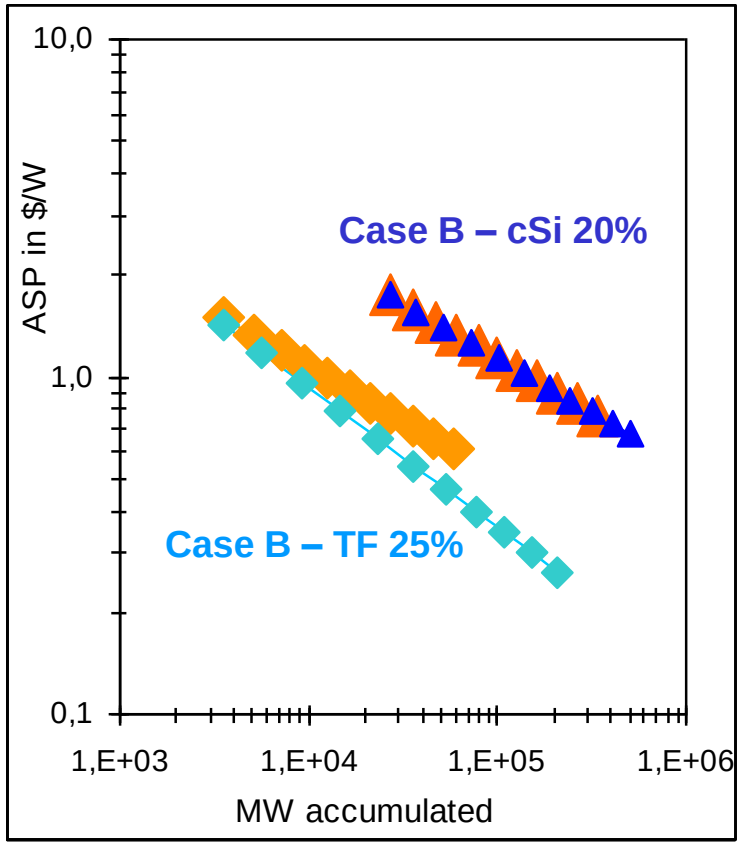
Volume Growth	Baseline				Paradigm Shift			
TF Share	15%		15%→35%		15%		15% →35%	
TF PEF	20%	25%	20%	25%	20%	25%	20%	25%
Case	**1**	2	3	4	5	6	7	**8**

Volume Scenarios



Photovoltaic – Future Price Development

PEC Scenario



Case A: Baseline
TF share 15% const
TF PEF 20%

Case B:Paradigm Shift
TF share 15% → 35%
TF PEF 25%

c-Si Technology
price expectation in 2020
ca. 60 – 80 $ct/W

Thin Film Technology
price expectation in 2020
ca. 30 – 70 $ct/W

BOS – Complete Systems Consideration

(2011)

Price Contribution (2009)

2.0

Price(total) **3.0€**

0.35

Price(power) **0.5€**

DC-AC inverters & approval procedures

0.45

+ Price(area) **0.7€**

mounting structure, cab-ling and installation costs

1.20

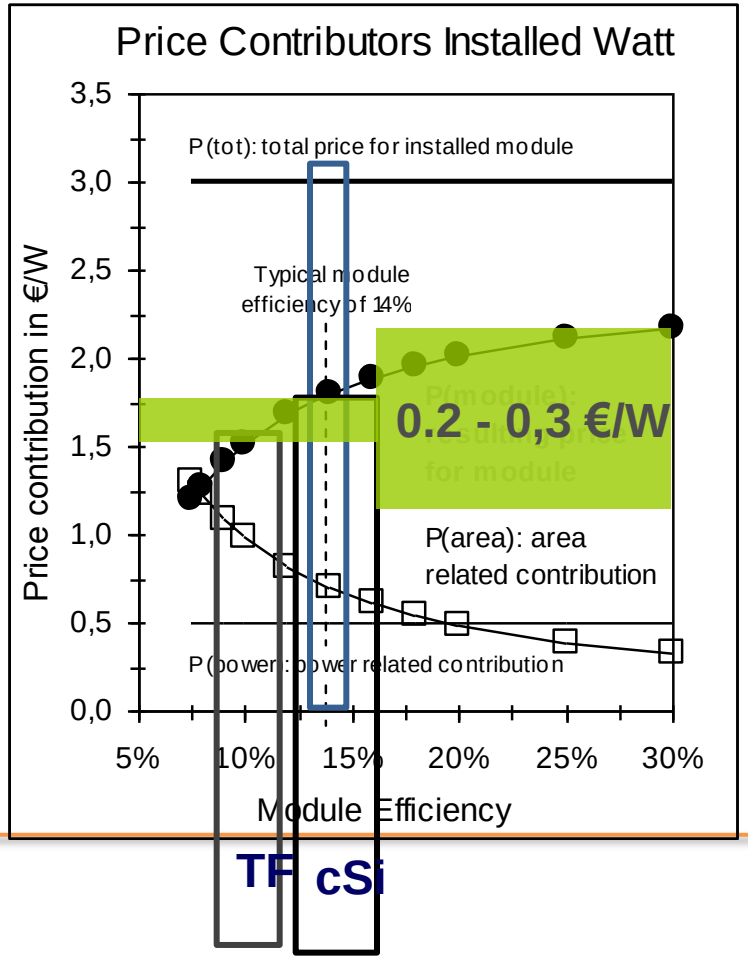
+ Price(module) **1.8€**

module price ex-works & a margin for the installer

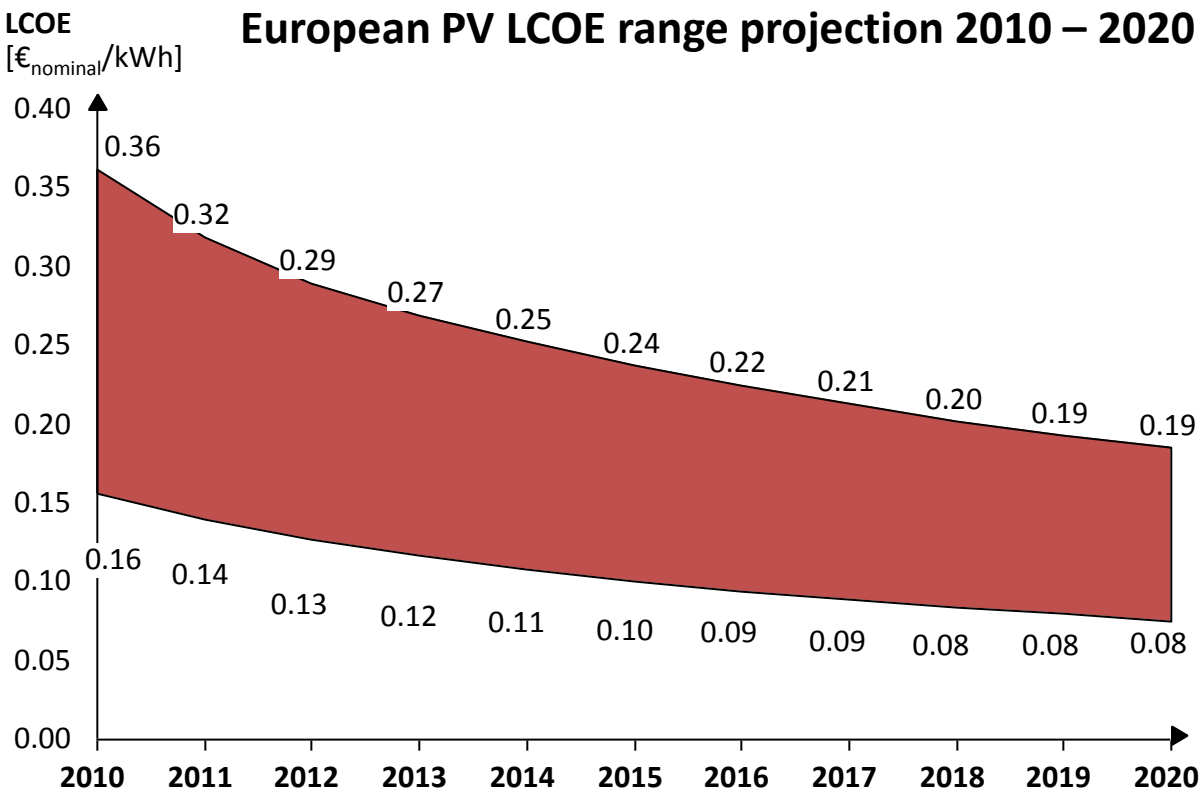
@ 15%

@ 14% Efficiency

Module Price vs. Efficiency



The levelized cost of PV generation in Europe is expected to decline by around 50% until 2020



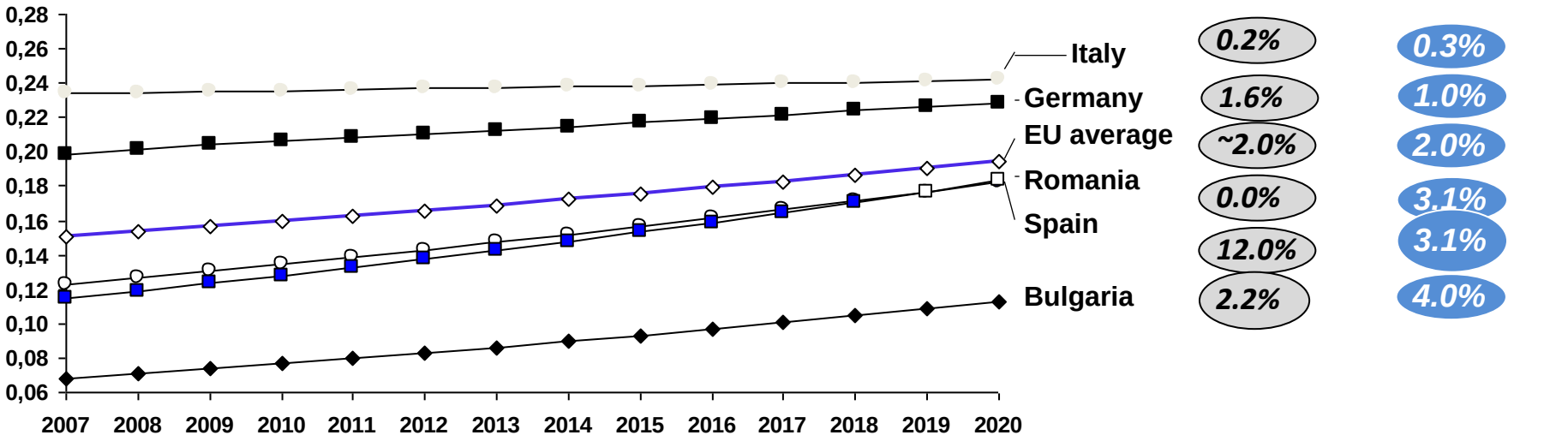
Band of LCOE reflects:

- Four different system size segments
- Crystalline Silicon and Thin Film technologies
- Differences in national installed system and operations cost
- Differences in national irradiation
- Different WACC for different countries considered
- VAT for residential segment

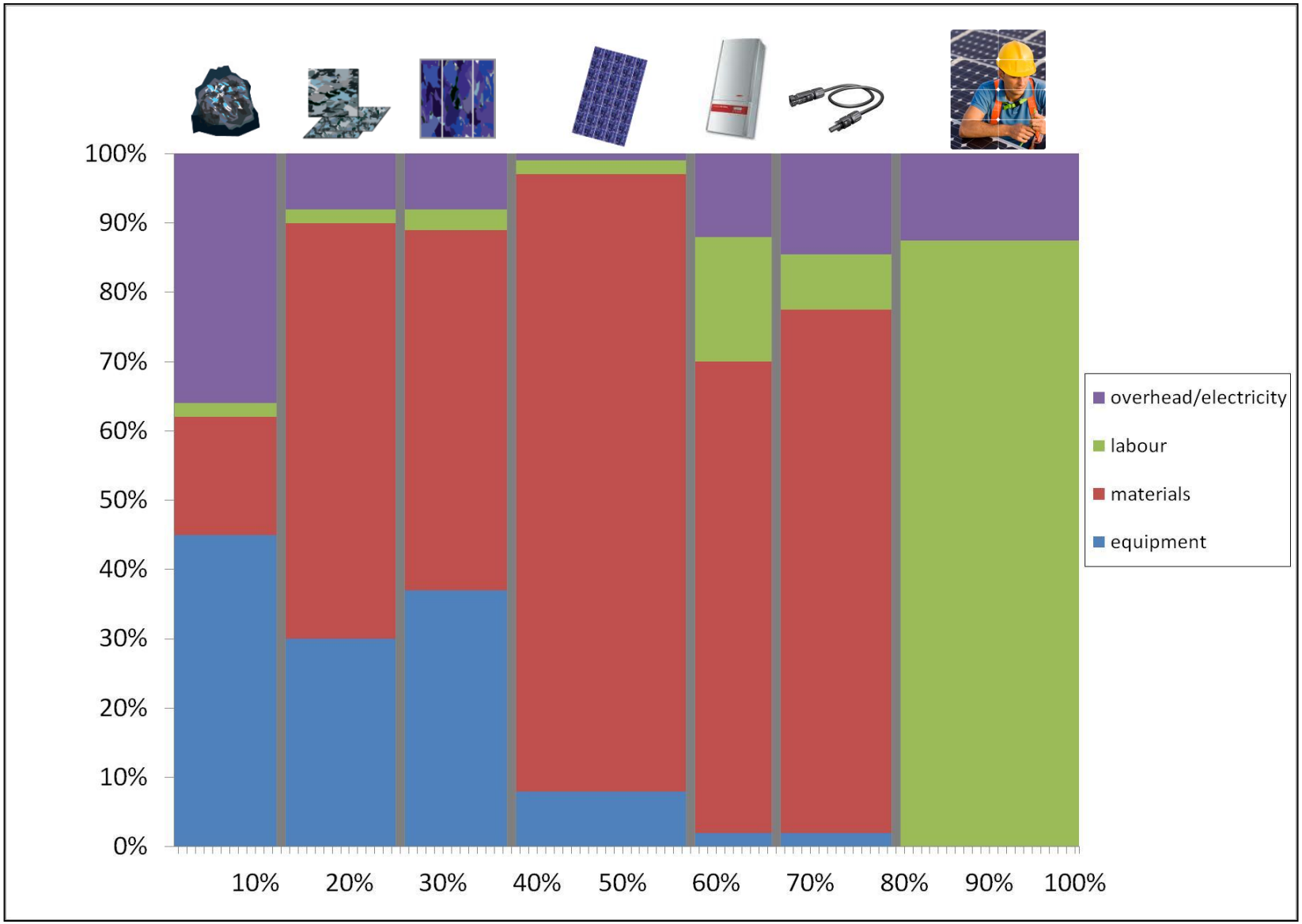
Thanks to Phoenix Solar for granting permission to A.T. Kearney to use existing cost model !

Source: EPIA/ A.T. Kearney / Phoenix Solar LCOE model; various input sources

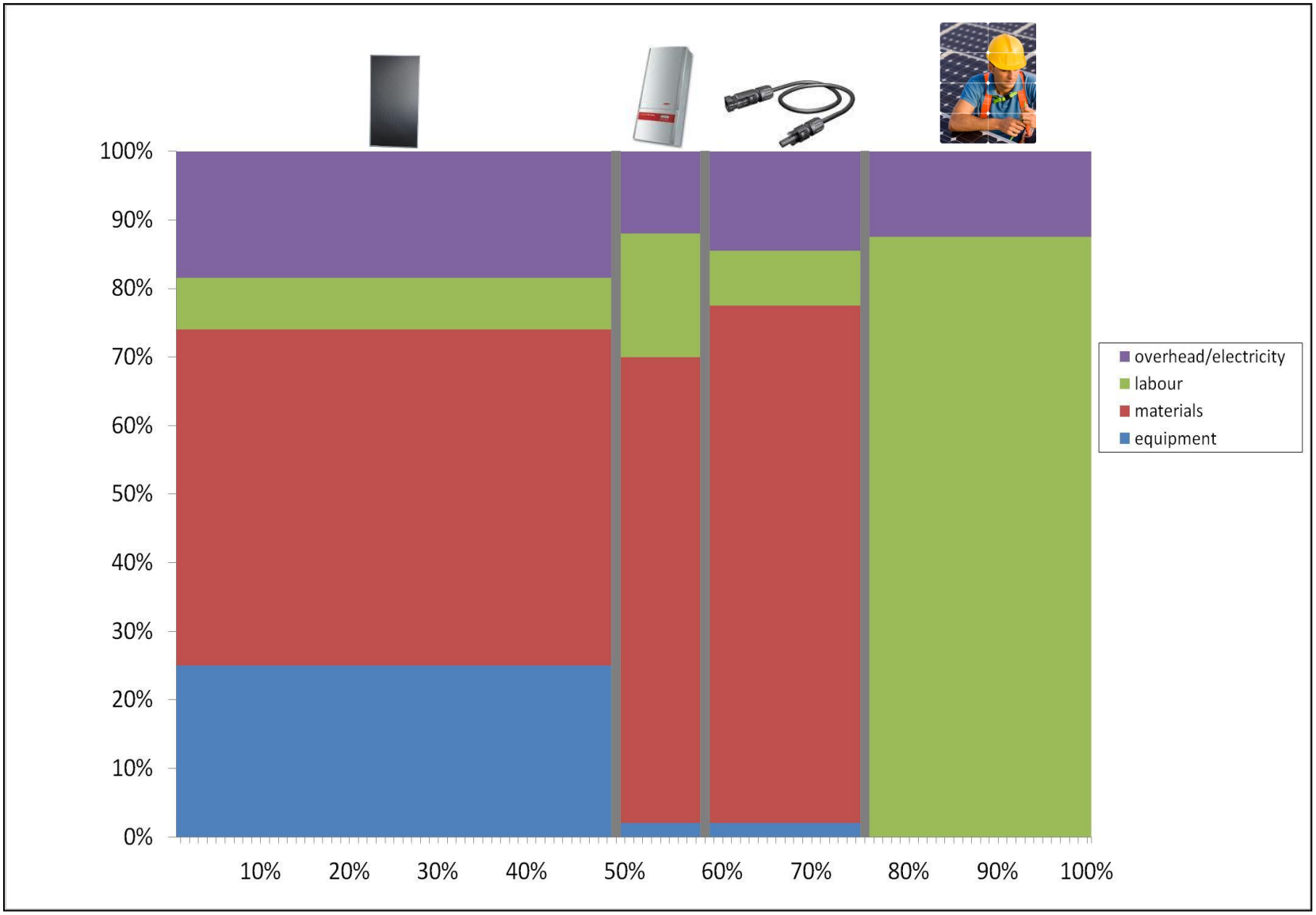
Evolution of residential grid electricity prices (€/kWh)



Marimekko graph for c-Si systems



Marimekko graph for TF PV systems



Extrapolation from „Marimekko 2010“ to 2020

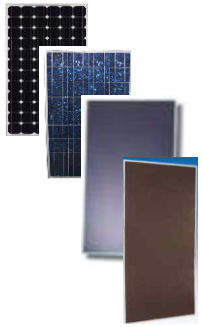
year	2 0	1 0	→	2 0	2 0
C-Si efficiency	15%		→ 15/20 = 0.75	20%	
	MM‘10 [%]	[€/W]		[€/W]	[%]
Module	60	1.68	PEC c-Si	0.70	47
Inverter	8	0.22	PEC	0.11	7
BOS	12	0.34	Eff. Factor 0.75	0.25	17
Installation	20	0.56	Eff. Factor 0.75	0.42	29
total	100	2.80	→	1.48	100

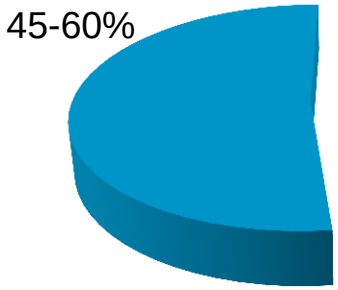
Extrapolation from „Marimekko 2010“ to 2020

year	2 0	1 0	→	2 0	2 0
TF efficiency	12%		→ 12/16 = 0.75	16%	
	MM‘10 [%]	[€/W]		[€/W]	[%]
Module	50	1.30	PEC TF	0.50	35
Inverter	9	0.22	PEC	0.11	8
BOS	16	0.42	Eff. Factor 0.75	0.32	22
Installation	25	0.66	Eff. Factor 0.75	0.49	35
total	100	2.60	→	1.42	100

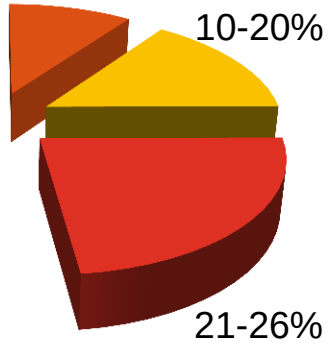
From PV module to PV system

PV modules

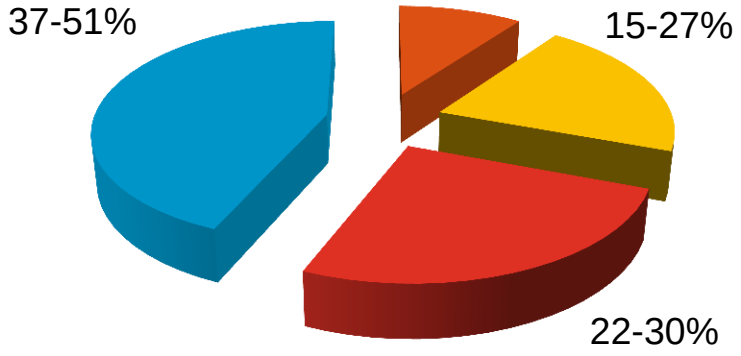




PV inverter



Balance of system

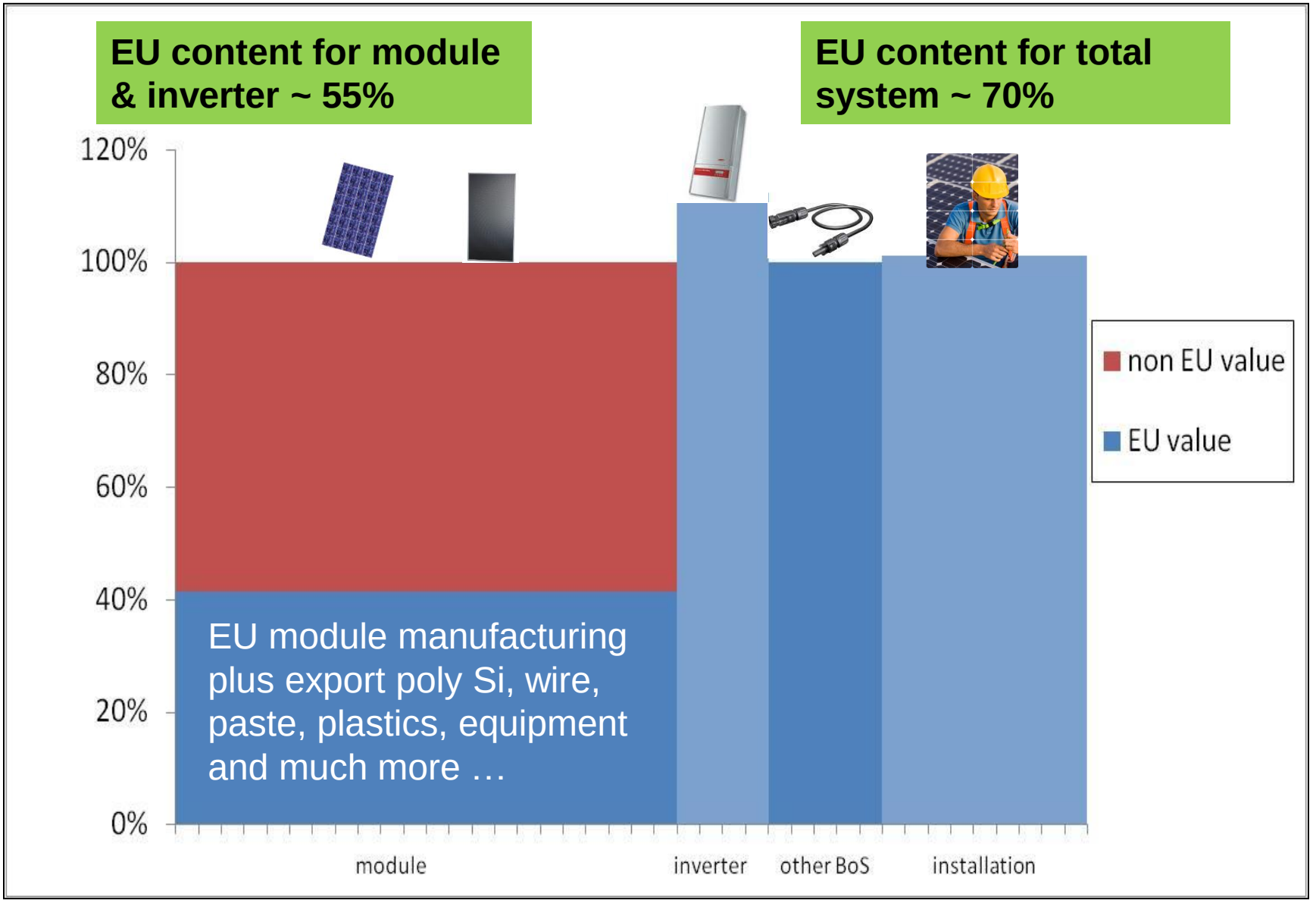


Installation

2010

2020

Photovoltaics & added value in Europe



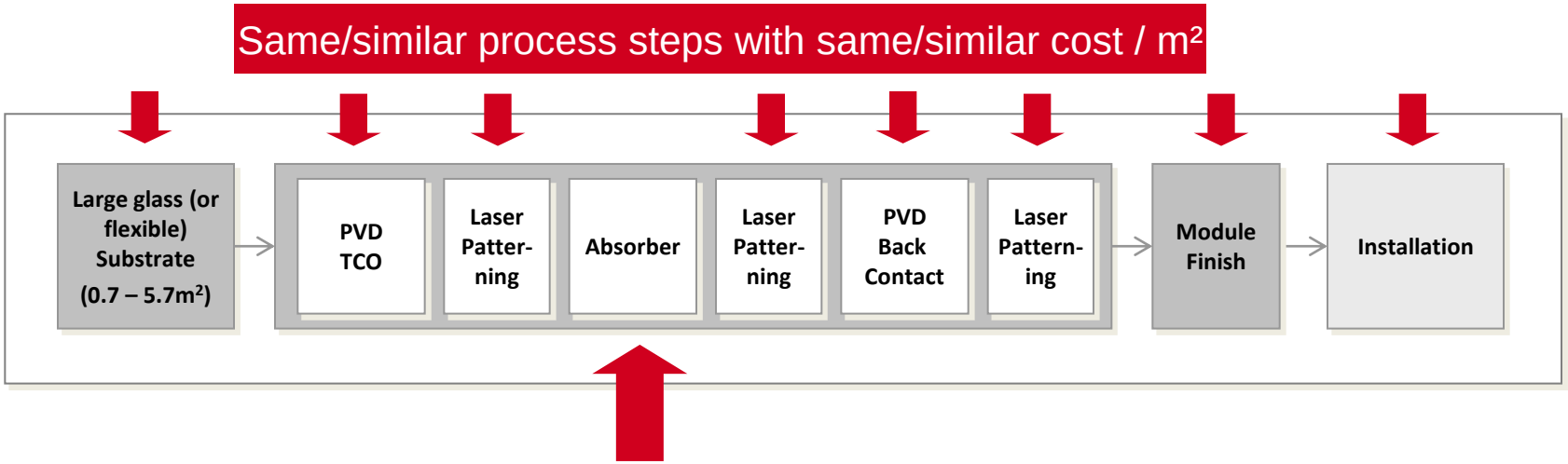
Building Integrated Photovoltaic (BIPV)

Project: **SCHOTT Solar**

Location: **Alzenau**

Function: **Façade of Production building**

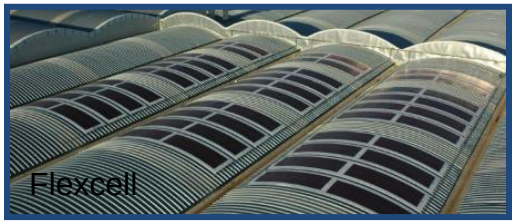
Thin Film PV Value Chain



Thin Film Silicon	PECVD a-Si and µc-Si (6 ... 10 → 7 ... 12)
CIGS	co-evaporation (10 ... 12 → 13 ...15)
	Sputtering and selenization (9 ...11 → 12 ...14)
CdTe/CdS	close space sublimation (9 ... 11 → 10 ...12)

Different processes and material cost for absorber formation

Flexible Solar – Expanding Applications



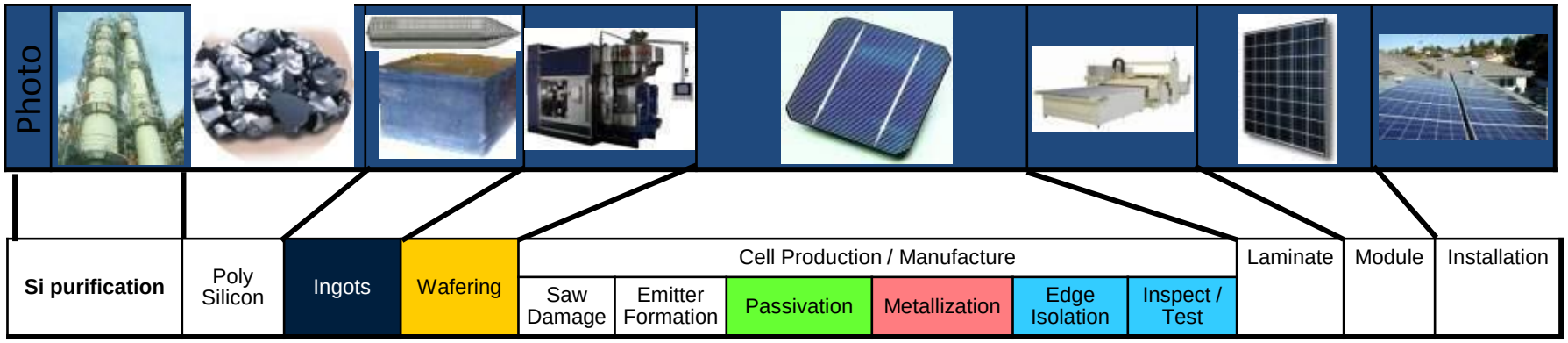
- Lightweight
- Conformable

- Building Integrated PV
- Non-Rigid Applications

Traditional Thin Film Technologies: a-Si, a-Si/µc-Si, CTS, CI(G)S

- Large area deposition technologies for all layers (PVD, CVD)
- High deposition rate technologies with high performance layers
- Innovative cell architectures for higher efficiencies

c-Si value chain

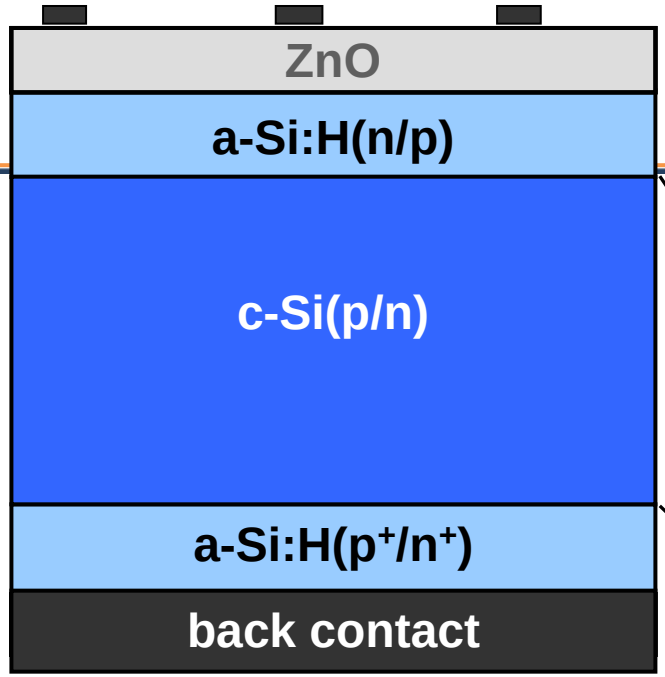


Relevant steps for vacuum deposited thin films:

 # ARC/passivation: from AP-CVD TiO2 to PE-CVD or PVD SiNx

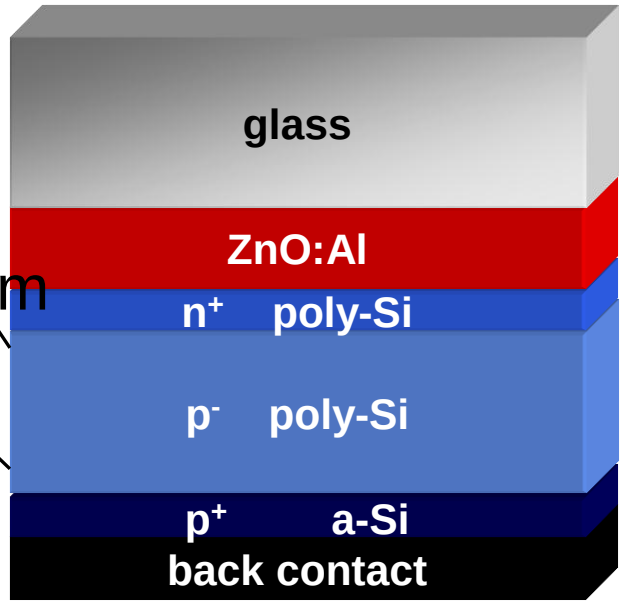
 # metallization: from evaporated Ti-Pd-Ag to screen printing of Al- (back) and Ag- (front) paste towards future Al - evaporation

The next step: new Materials and Devices, the Si-Path@HZB



200 µm

<10 µm

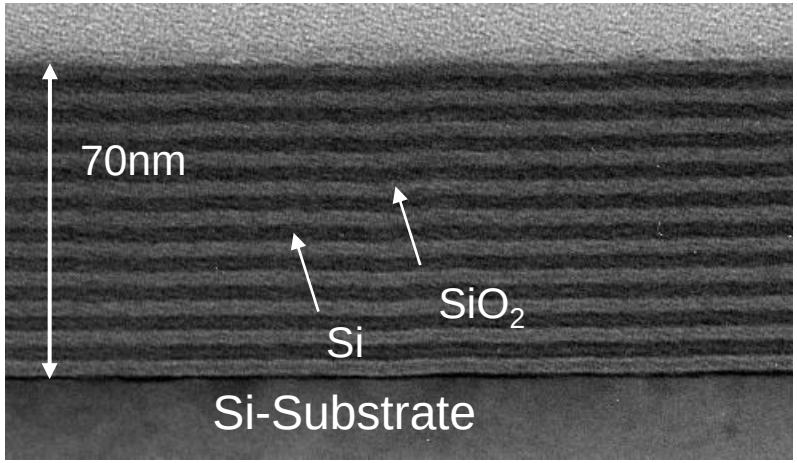


Today´s efficiency @ HZB ~20 %
Si-thickness: 200 µm (HIT cell)

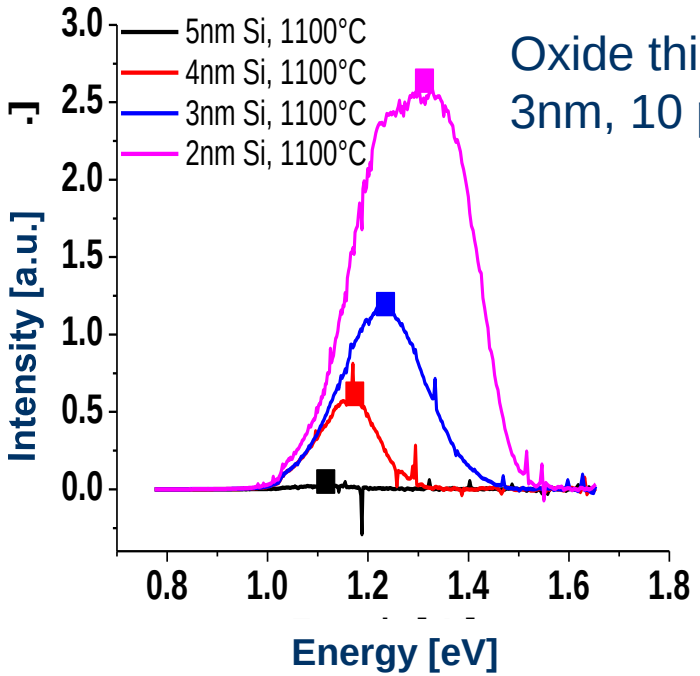
efficiency goal (long term): 20 %
Si-thickness: < 10µm

Enhance the Absorption

Si/SiO2-Super Lattice for Band Gap Shifting



As deposited (amorphous Si-layers)

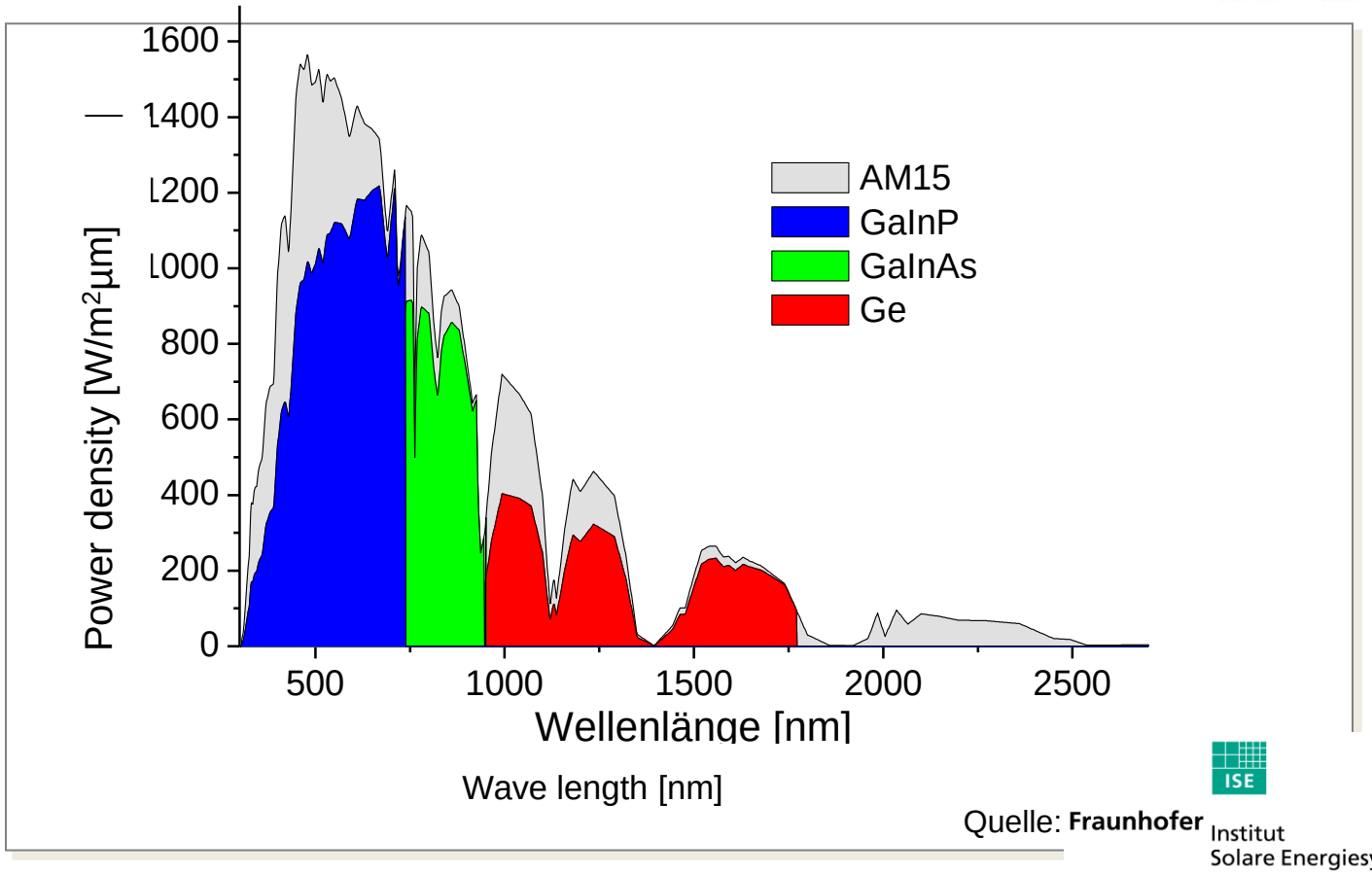


Oxide thickness:
3nm, 10 periods

Source: IHT RWTH Institut für Halbleitertechnik

Multi Junction Solar Cells

Combine Materials with Different Absorbance Behaviour



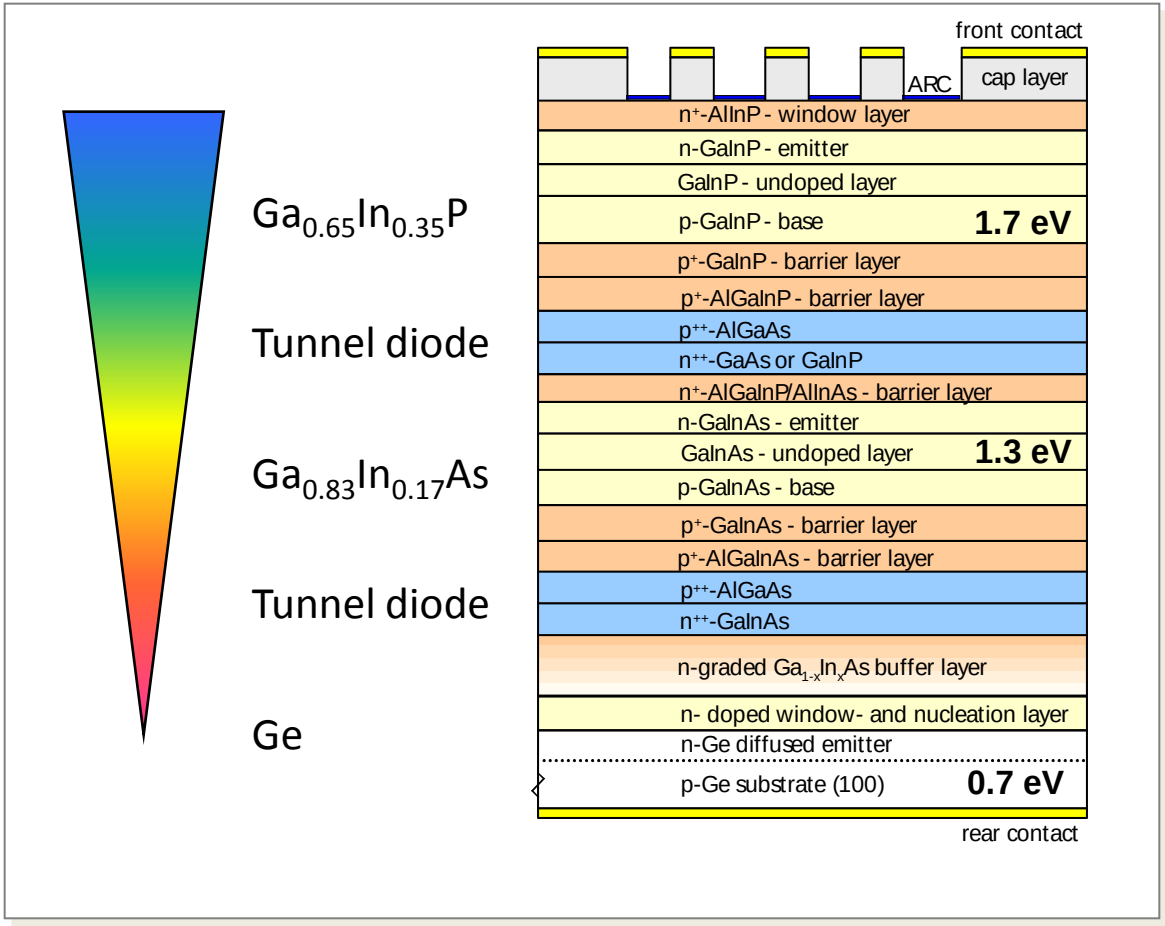
Quelle: Fraunhofer Institut Solare Energiesysteme

61

Photovoltaic Optoelectronics

Recent world record of
41% at 500x concentration

Source ISE
Fraunhofer Institut Solare Energiesysteme



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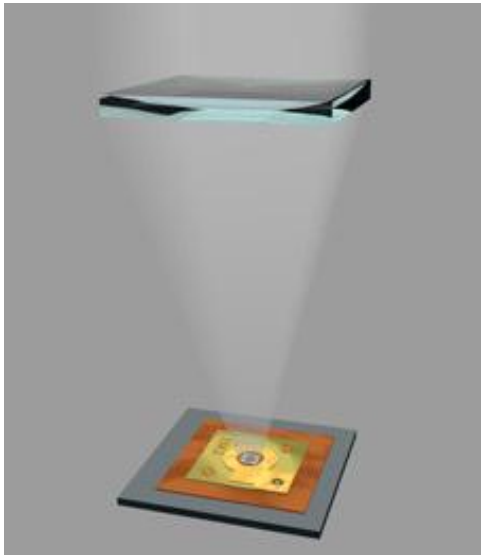
Concentrated PV

Combine Mutli-Level Junctions with Optical Magnification

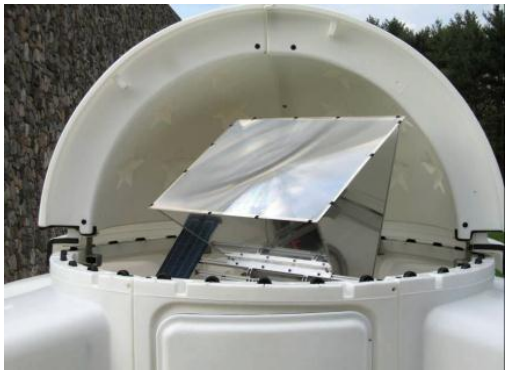


Challenges

- High efficiency solar cell
- Optical system with tracking systems
- Cooling the solar cell

IBM:

Concentration x2000, liquid metal cooling system with thin layer of Ga and In



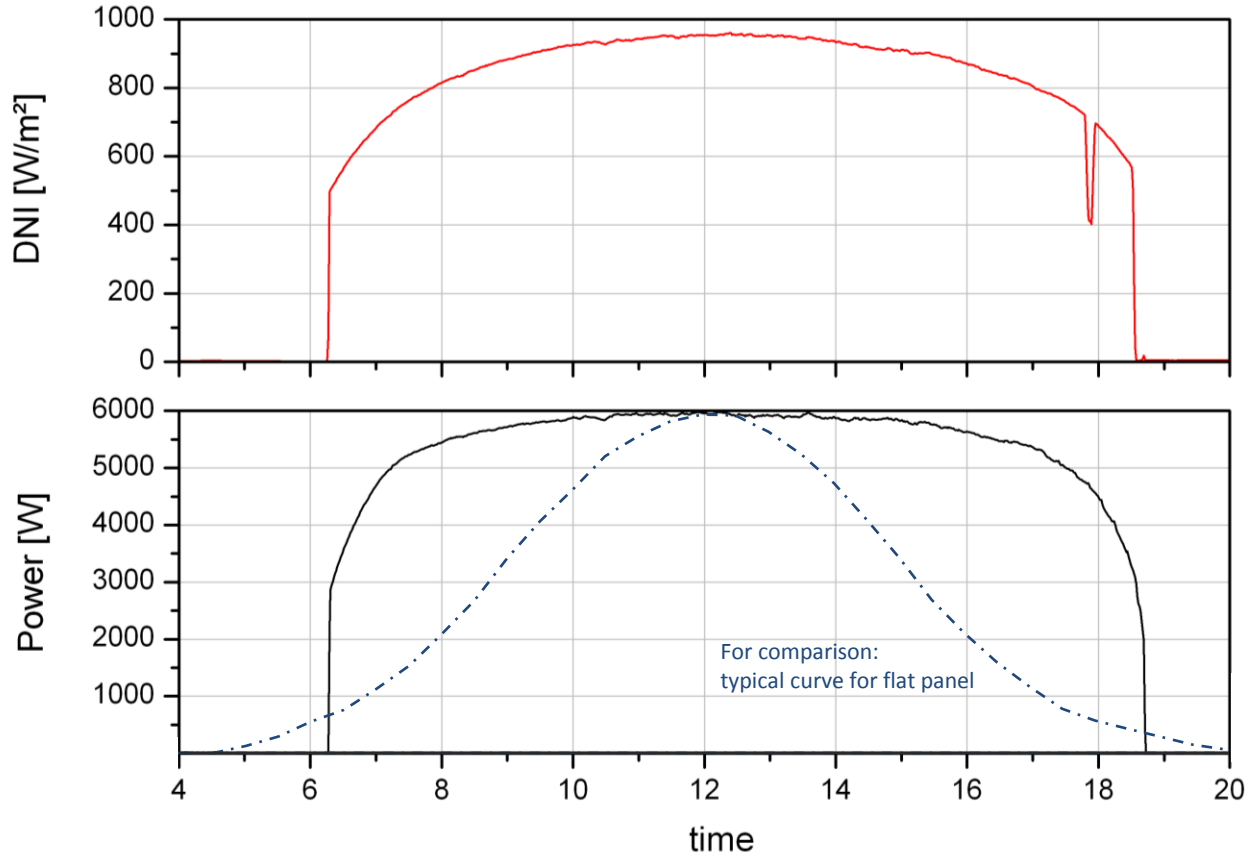
High Optical Concentration Photovoltaic

Lorca, Spain

Source: Concentrix Solar

Performance of a Concentrix System

5,8 kW Nominal Power



Data: July 27th 2008, Seville Spain

Technology Evolution

r ribbon

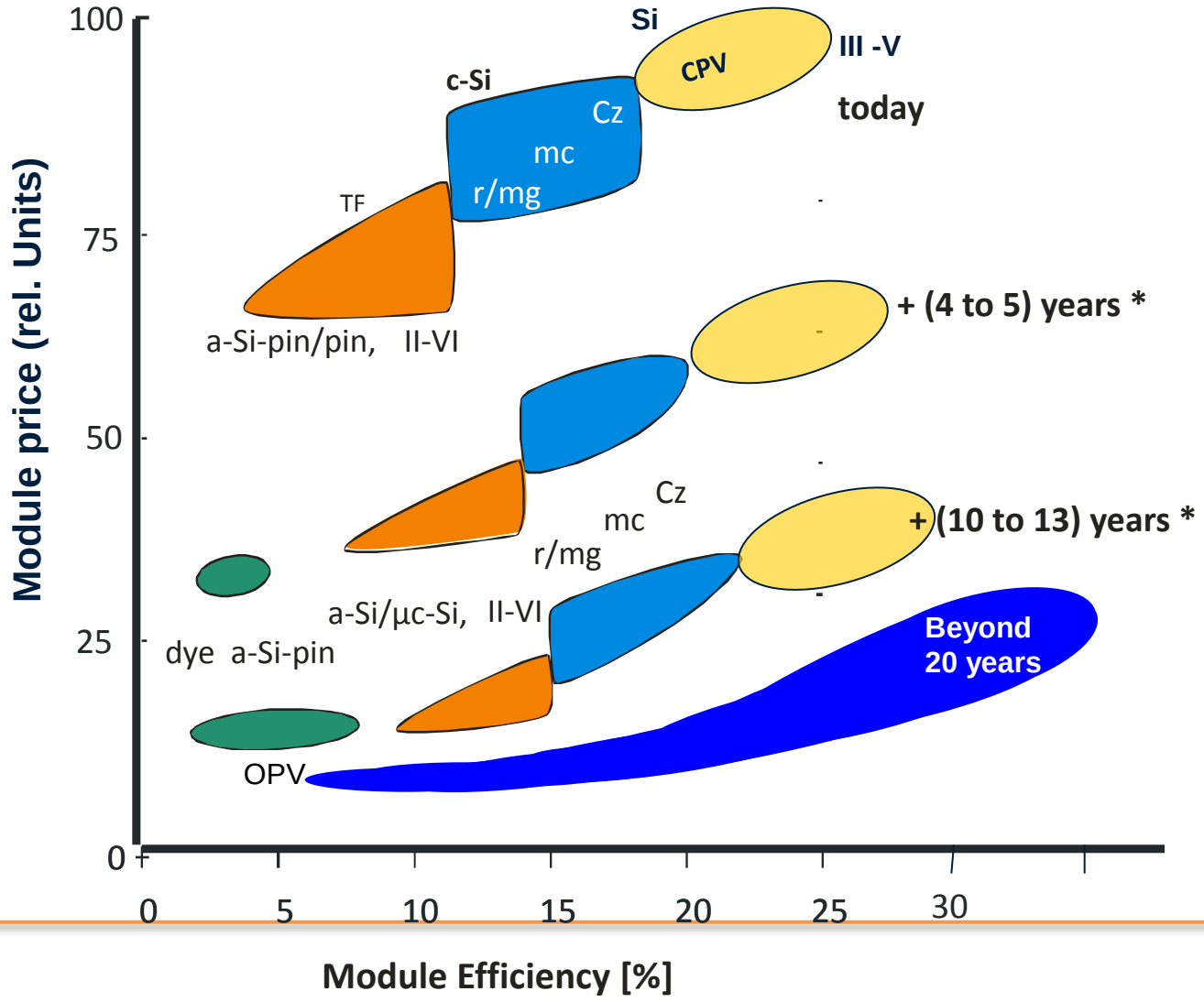
mg metallurgical grade Silicon

mc multicrystalline

Cz Czochralski

CPV concentrated PV

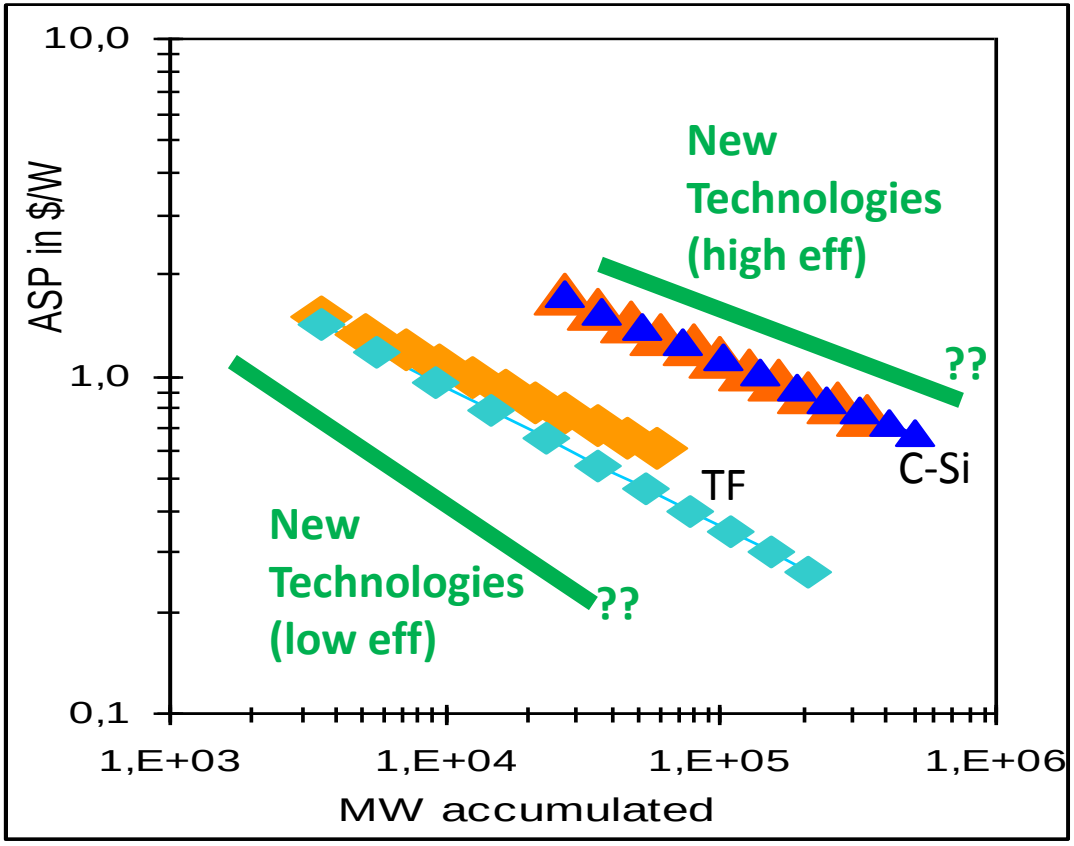
OPV organic PV



@ - (8 to 10) % price decrease per year

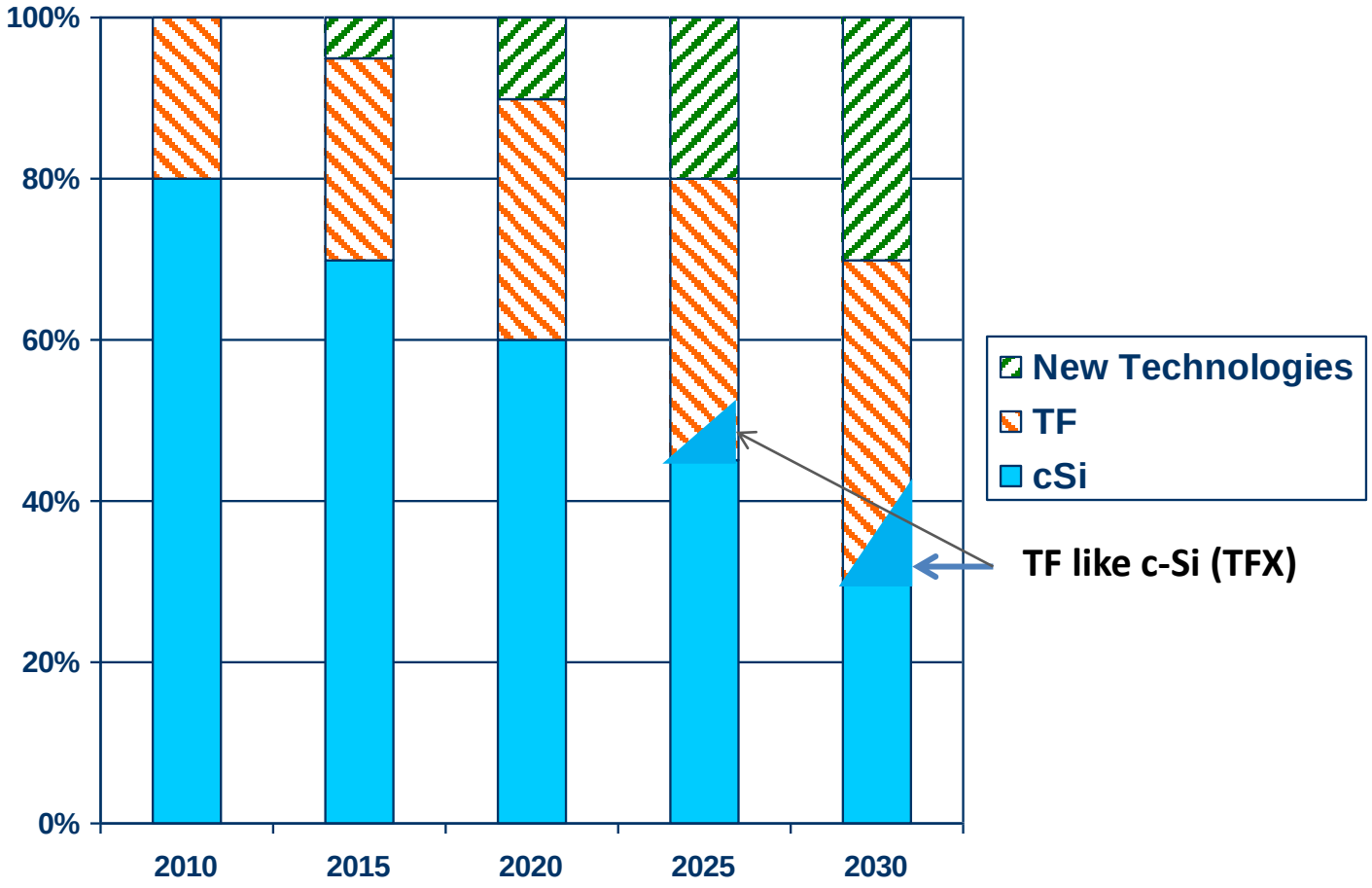
ref: W. Hoffmann personal estimates

PEC for c-Si, Thin Film and tentative New Technologies 2010 to 2020



Source: Winfried Hoffmann, own estimates (06/2011)

Share of PV Technologies



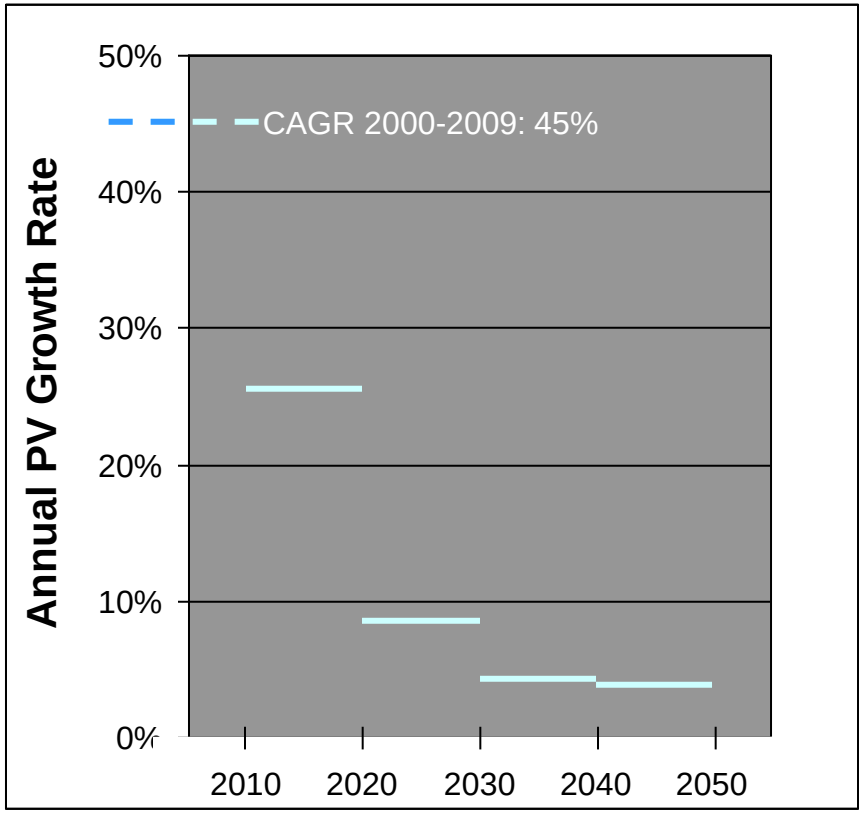
Source: W. Hoffmann, personal estimates, (2008/2011)

RES-thinking 2050

Worldwide PV Growth Scenario till 2050

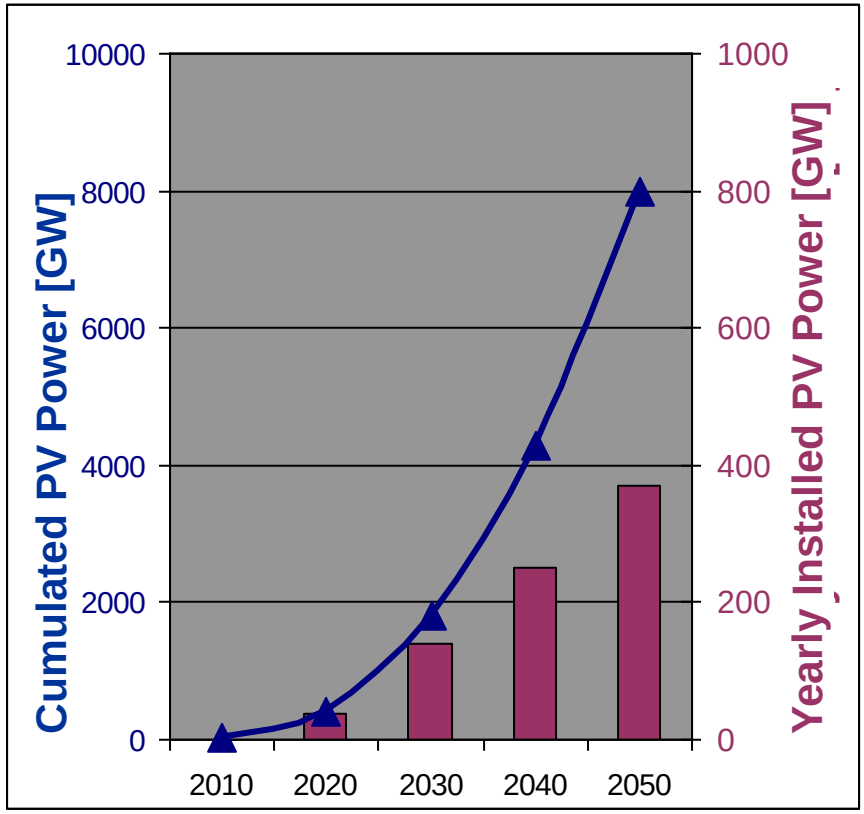
A-S-E

PV Growth Rate



Ref: EREC and EPIA 2010 and own estimates

PV Volume Growth

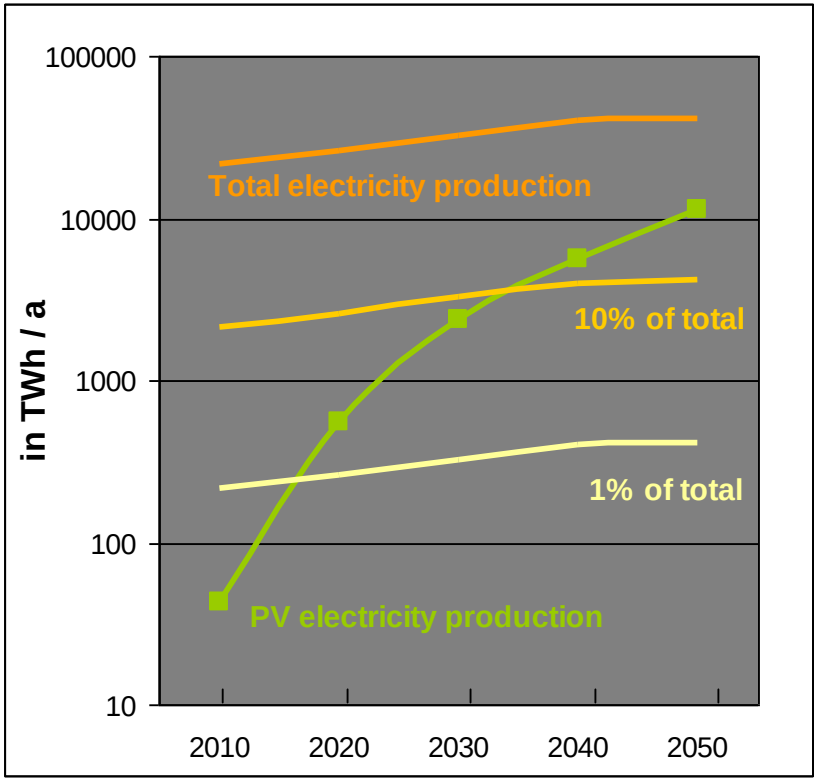


Source: EREC RES-Thinking, 03/2010 and own estimates

RES-thinking 2050 – World

PV Growth Scenario till 2050

PV Growth

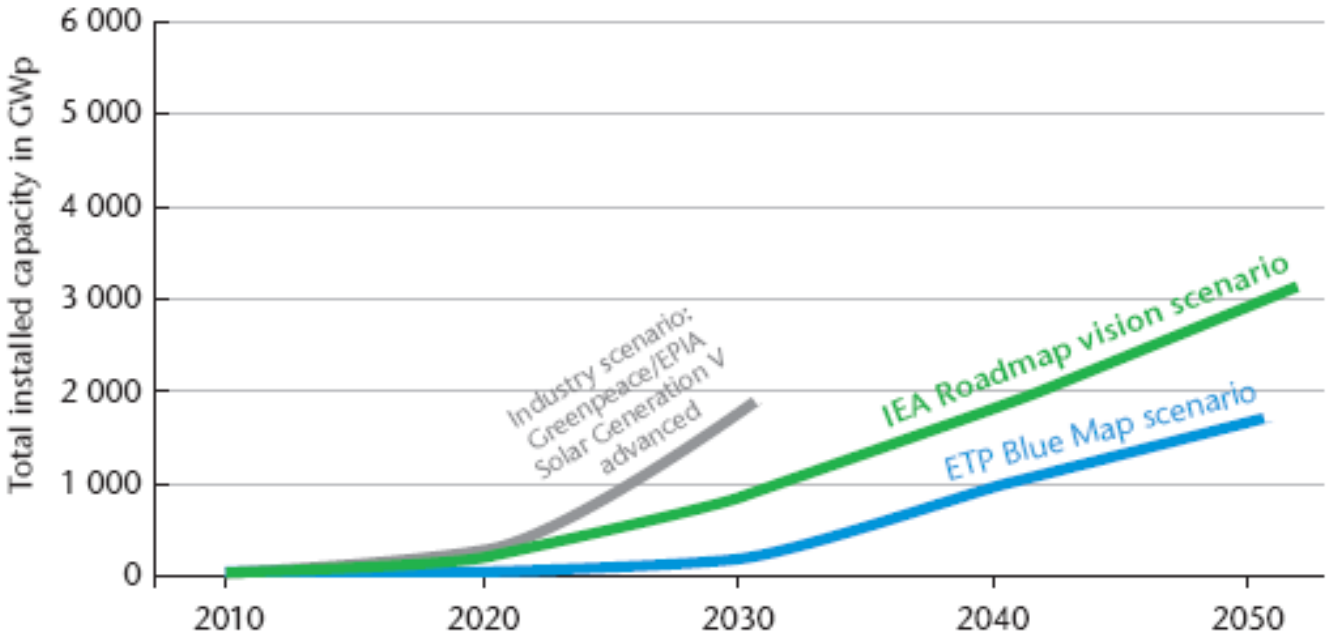


Assumption for 2050

- EU-27
  - 100% target for RES of final energy
  - All RES sources to contribute
  - 43% electricity share assumed (vs. 37% in [r]evolution scenario)
- World (OECD)
  - 80% target for RES of final energy
  - 43% electricity share assumed, too
  - PV covers about 1/4 of electricity and about 1/6 of final energy demand
  - Total PV energy supply in 2050: 11k TWh/a

Ref: EREC 2010 and W. Hoffmann personal estimates

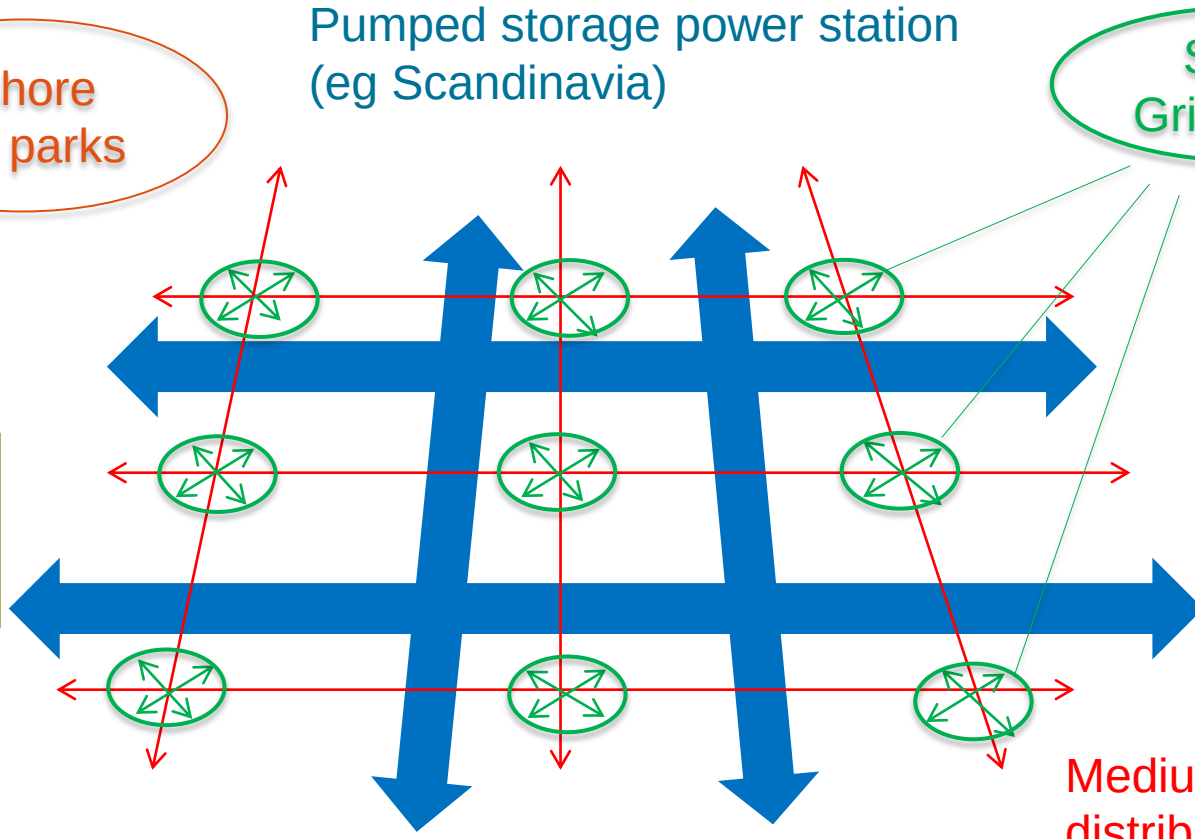
IEA PV Roadmap Vision



ETP 2010
Hi-RE Scenario

PV cumulative installed capacity to reach 900 GW in 2030 and 3000 GW in 2050

Super and Smart Grids



Source:

W. Hoffmann, own considerations, March 2011

PV grid integration measures according to cost/ benefit ratio and ease of implementation

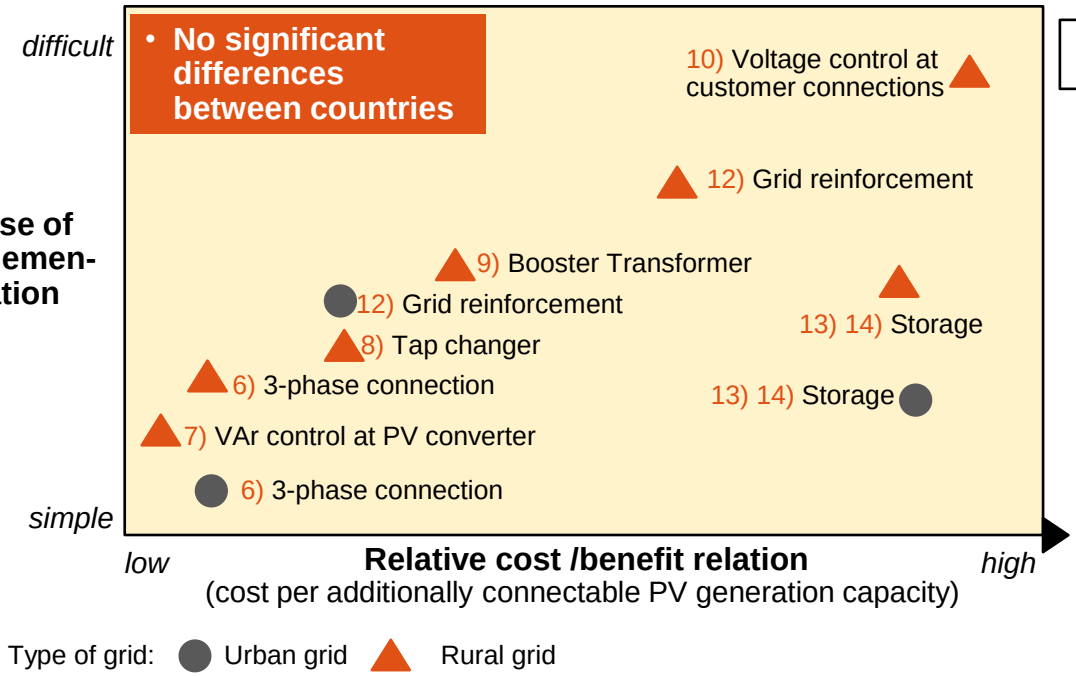
4 scenarios – only B and C for further considerations

A – Pessimistic
- Low network reserve
- Decreasing homogeneity (20%)

B – Conservative
- Low network reserve
- Today's homogeneity (30%)

C – Realistic
- High network reserve
- Today's homogeneity (30%)

D – Optimistic
- High network reserve
- Improving homogeneity (60%)



Example: German distribution grid

Type of grid: Urban grid Rural grid

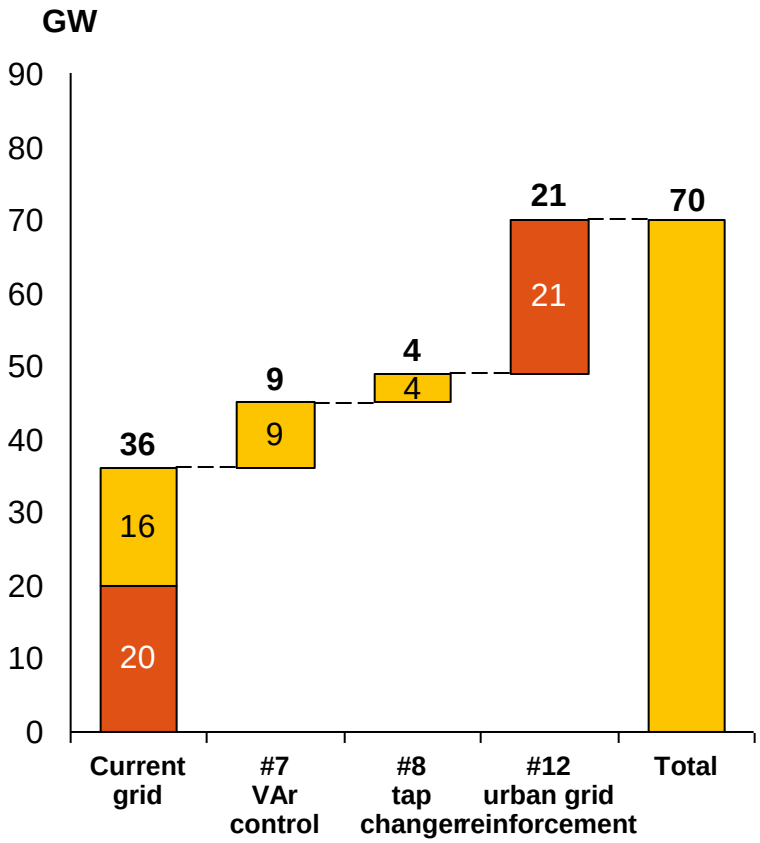
Source: Consentec assessment; Workshop discussions

PV hosting capacity can be increased further with additional measures in order of economic viability

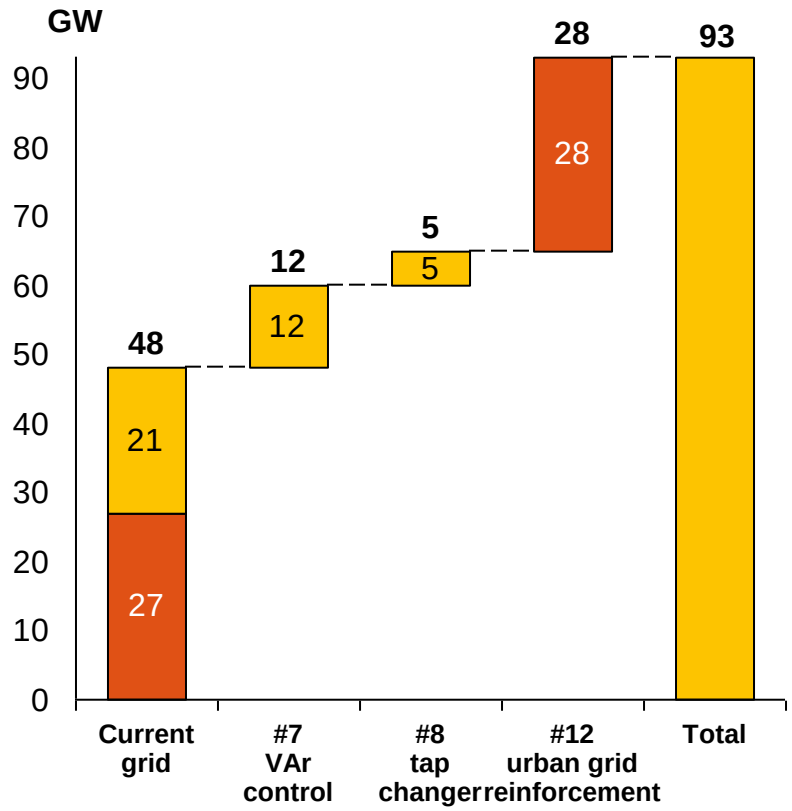
III Expansion of hosting capacity through measures

Example Germany

Conservative scenario



Realistic scenario



Rural Urban

Source: Consentec analysis; EPIA and A.T. Kearney Workshop inputs

High Level Group (HLG) working on Key Enabling Technologies (KET)

3 commissioners

27 HLG members from EU member states, industry representatives, R&D organizations and EIB
… assisted by many „sherpas“

HLG KET mid-term meeting

09 February 2011, Brussels

Máire Geoghegan-Quinn
Commissioner *(Abs. on picture)*

Commissioner Tajani

KETs in the Industrial Policy Initiative

-Key challenge:

"urgently develop and bring to market Europe's research strengths in emerging technologies "(page 13)

-*" KETs can provide the basis for a wide variety of new processes, goods and services, including the development of entirely new industries over the next decade"* (page 13)

Vice-President, Tajani
Commissioner for
Industry and Enterprise

EUROPEAN COMMISSION

Brussels,
COM(2010) 614

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

An Integrated Industrial Policy for the Globalisation Era
Putting Competitiveness and Sustainability at Centre Stage

Commissioner Kroes

KETs in the Digital Agenda

Promoting " Industry-led initiatives for open innovation bringing together stakeholders around common research agendas in areas such as key enabling technologies in ICT " (page 24)

Vice-President Kroes, Commissioner for Digital Agenda

EUROPEAN COMMISSION

Brussels, 26.8.2010
COM(2010) 245 final/2

CORRIGENDUM:
Annule et remplace le document COM(2010) 245 final du 19.5.2010
Concerne toutes les versions linguistiques

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

A Digital Agenda for Europe

Commissioner Geoghegan-Quinn

KETs in the Innovation Union

-The transversal and specific role of KETs in the next European Innovation Partnerships (EIPs) (page 12).
-Promoting world-class research Infrastructures (page 10).
- Developing Industry-driven partnerships on KETs (page 12).
-Clarifying state aids policy concerning KETs (page 15).
- Basing regulatory frameworks with regard to KETs on scientific evidence with transparent information and involvement of citizens (page 12).

Commissioner Geoghegan-Quinn for Research and Innovation

EUROPEAN COMMISSION

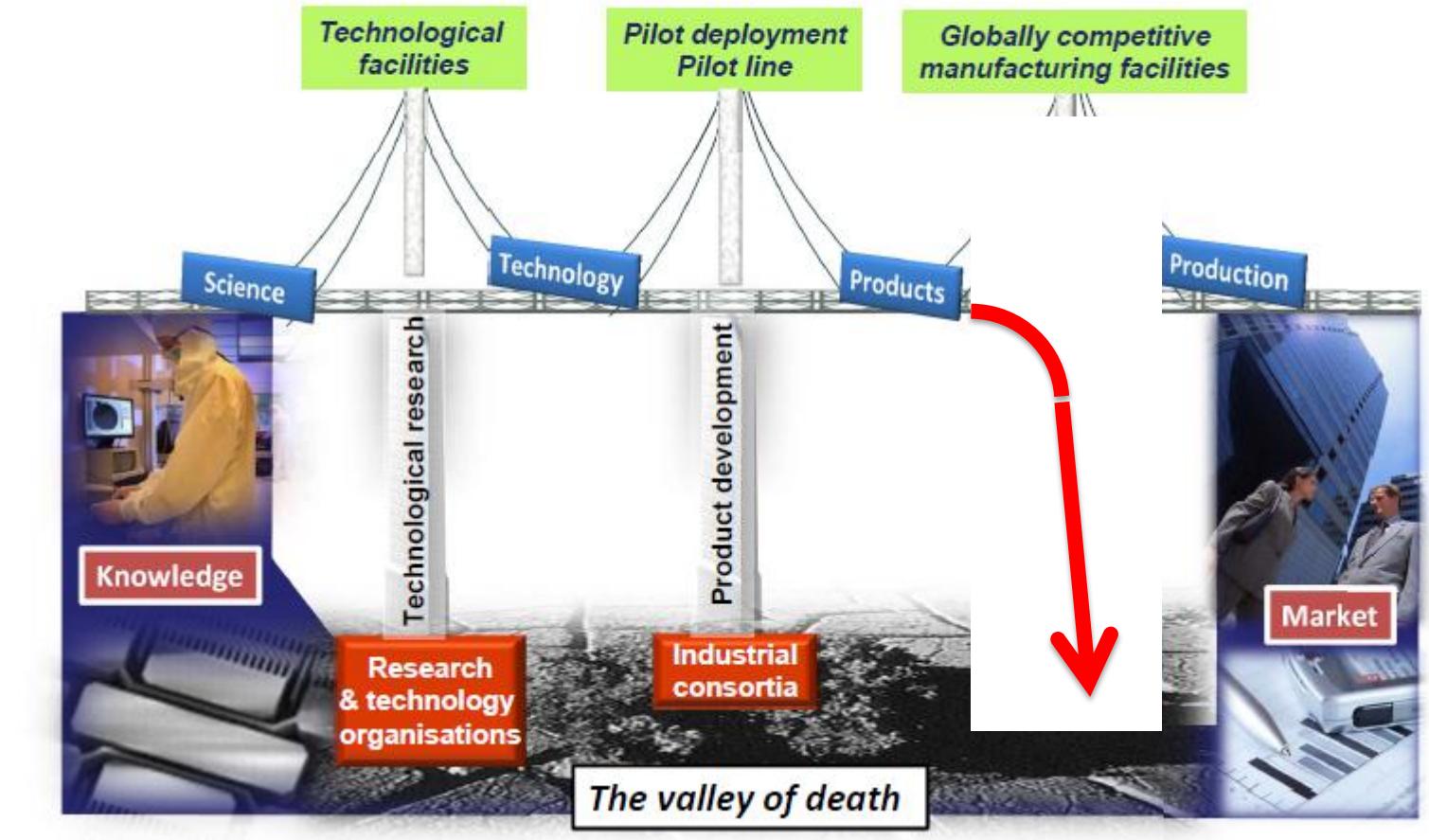
Brussels, 6.10.2010
COM(2010) 546 final

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

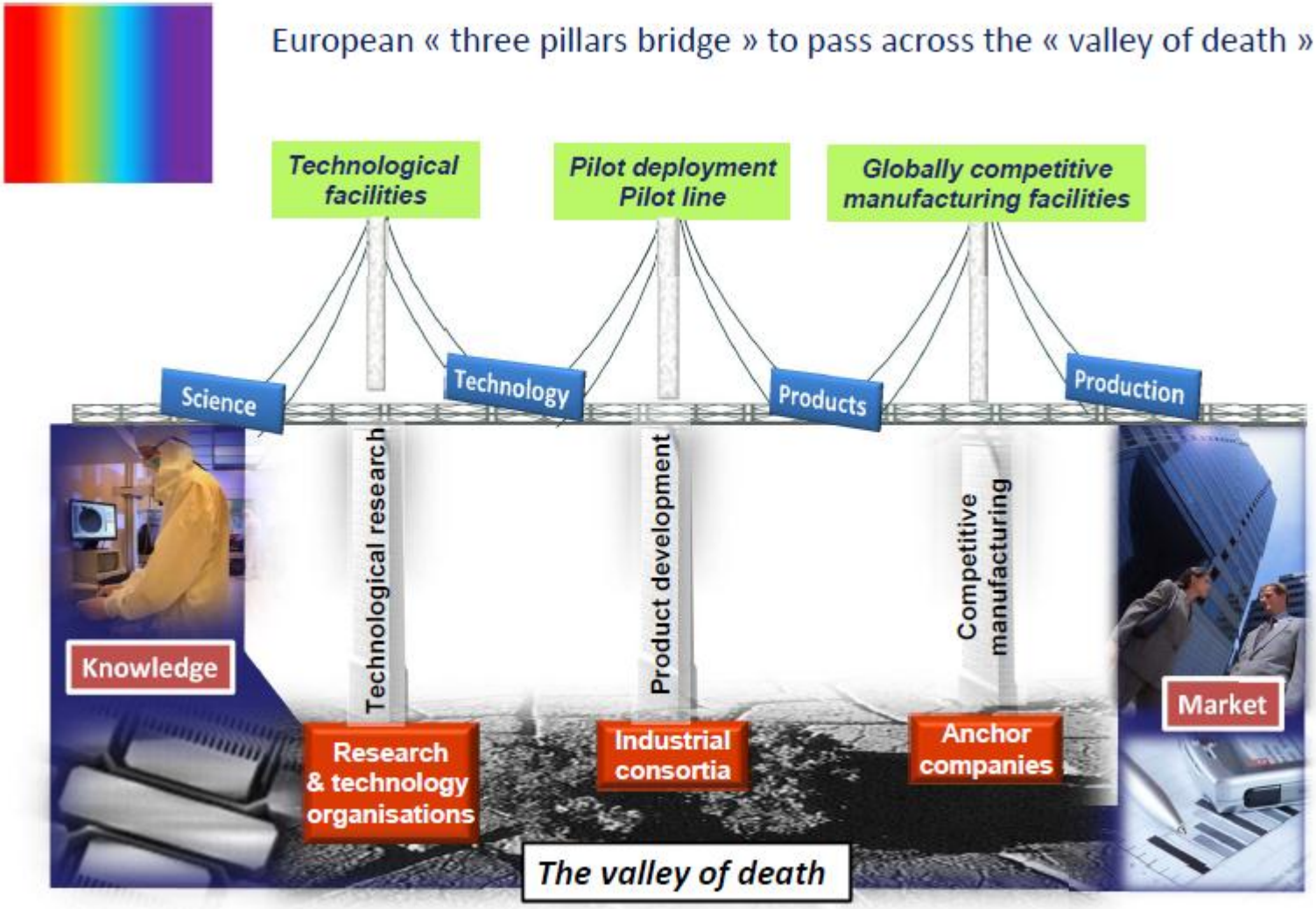
Europe 2020 Flagship Initiative
Innovation Union

SEC(2010) 1161

Valley of Death – EU focus in the past …
With consequences



Valley of Death



Applied Solar Expertise

Thank you for listening

… everyone who tries will find a way –

who doesn‘t try finds reasons!

Dr. Winfried Hoffmann – **ASE**
Vice President EPIA
Consultant Applied Materials Solar
Member of Scientific Board of FhG-ISE and Supervisory Board of ISFH and Helmholtz