Sun to Market Solutions

IFC – ESMAP – Renewable Energy Training Program
Solar Module

Technology, Market and Economics

June 16 – 18, 2014 IFC Washington, DC

Schedule

PV Technology Overview, Market Analysis, and Economics

PV Project Development, Implementation, and Financing

Case Study

Schedule

PV Technology Overview, Market Analysis, and Economics

- Introduction
- Industry and Market
- Technology Overview
- Economics

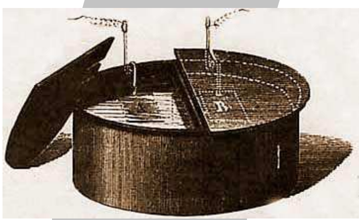
Is the PV a mature sector?

Have expectations been met?

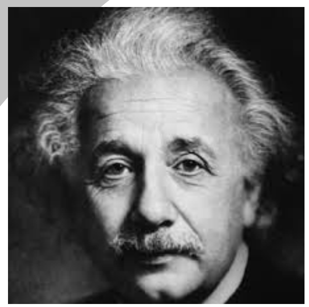
Background

PV theoretical foundations are recent. First terrestrial application was installed in the 50´s (some have not yet exceeded its useful life). Takeoff begins in 2000

electromagnetic waves
Heinrich Hertz,1885



First solar cell
Edmond Becquerel 1839



photoelectric effect
Albert Einstein, 1905

First silicon solar cell, Bell Labs 1954

Hoffman Electronics rises solar cell efficiency up to 14% from the existent 10%, 1950 -1960

70´s Word Energy Crisis: Big Industries start showing real interest on renewables

80´s – 90´s: "dark" times

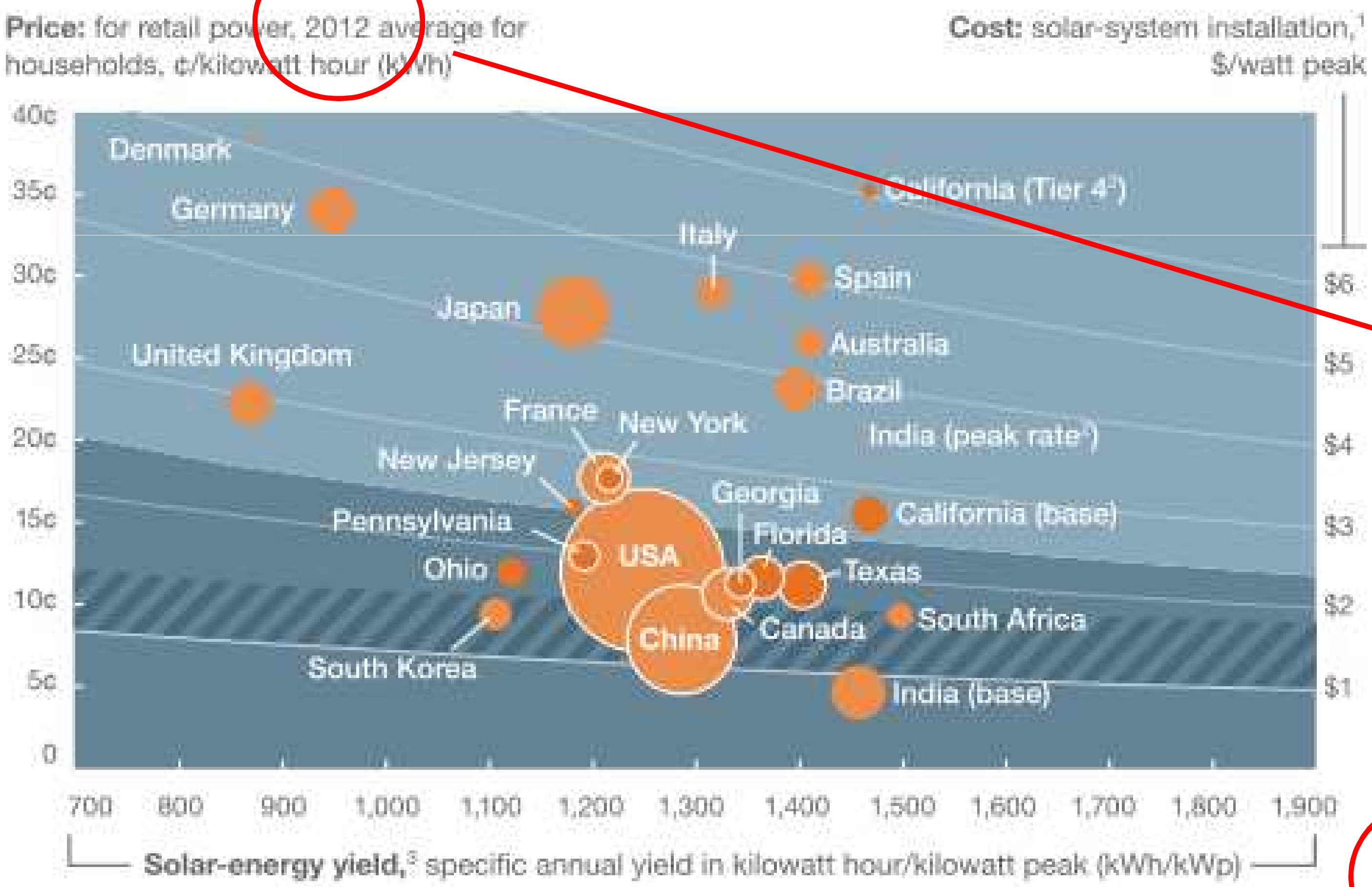
2000 – now: boom

Future : disruptive potential

Now

Nobody can forecast cost estimation. Costs fall too fast

Grid-parity potential of solar PV (photovoltaic) power in major markets, residential-segment example

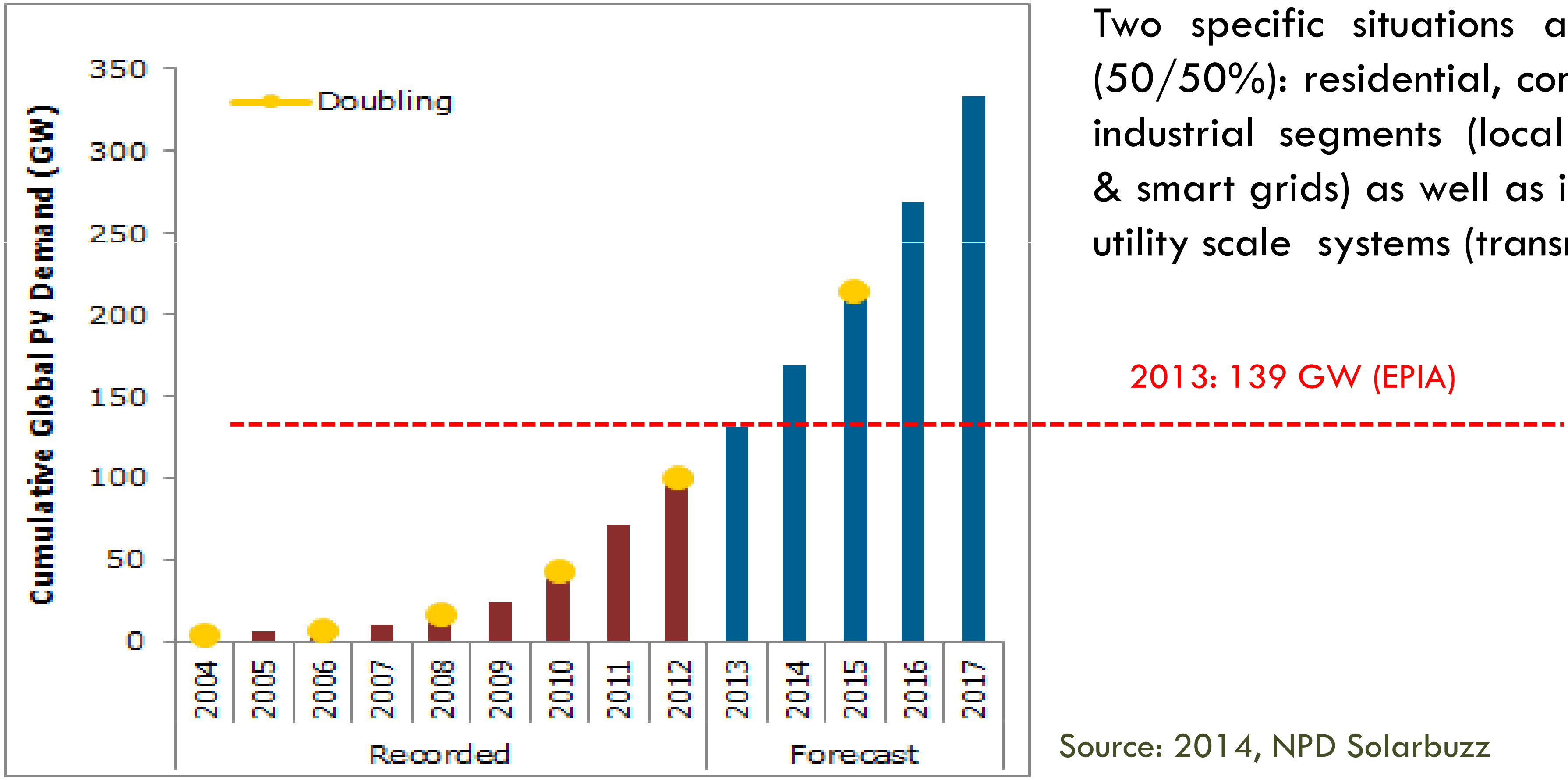


2012 data and report were published two years ago: the current situation can be 50 – 70% lower

2014 McKinsey & Company

Future

Forecast of cumulative installed capacity is between 300 and 400 GW for 2017

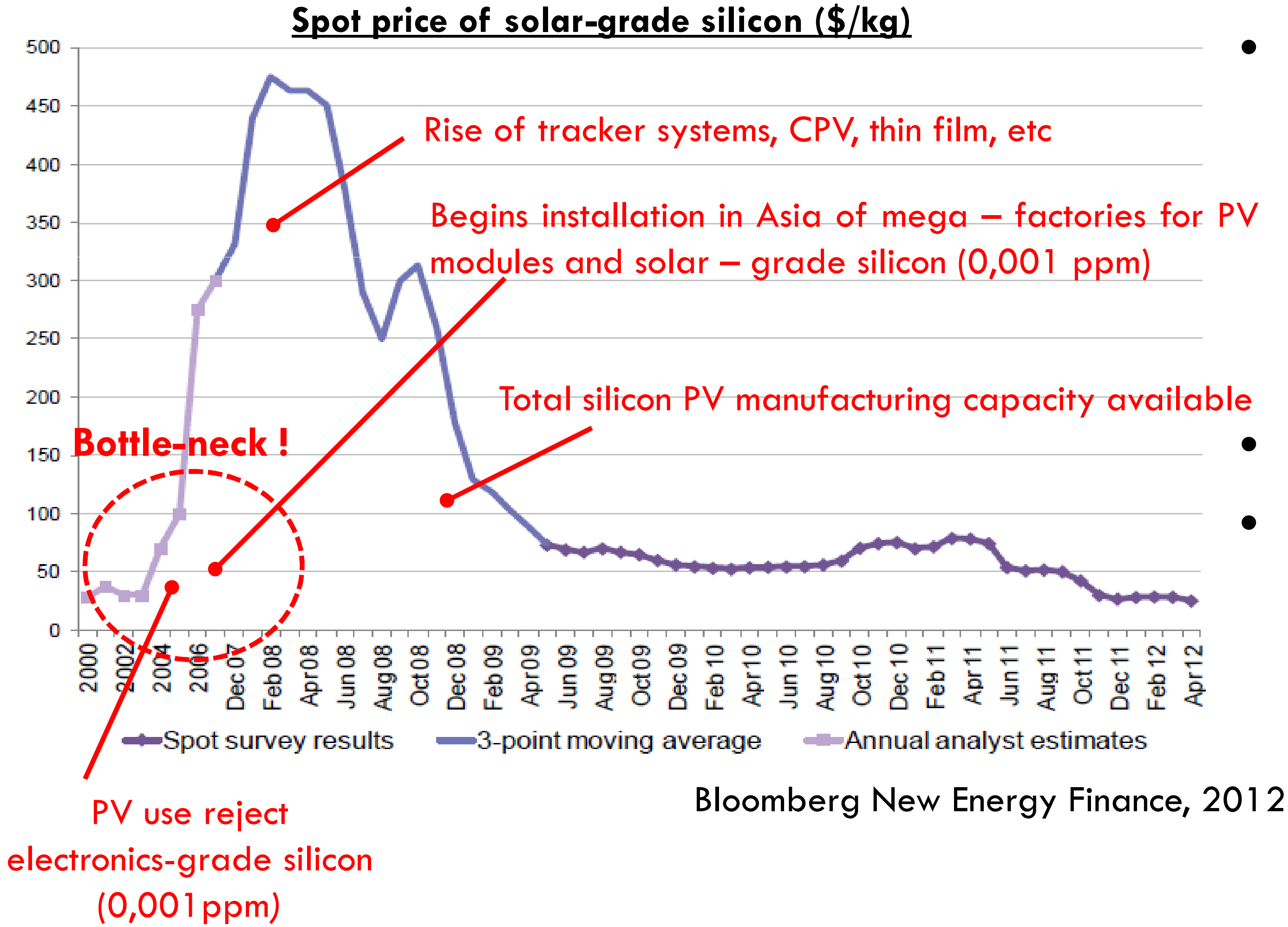


Two specific situations are expected (50/50%): residential, commercial and industrial segments (local consumption & smart grids) as well as industrial and utility scale systems (transmission grid)

Source: 2014, NPD Solarbuzz

How did it happen?

Real solar industry emerges in the 2000 decade



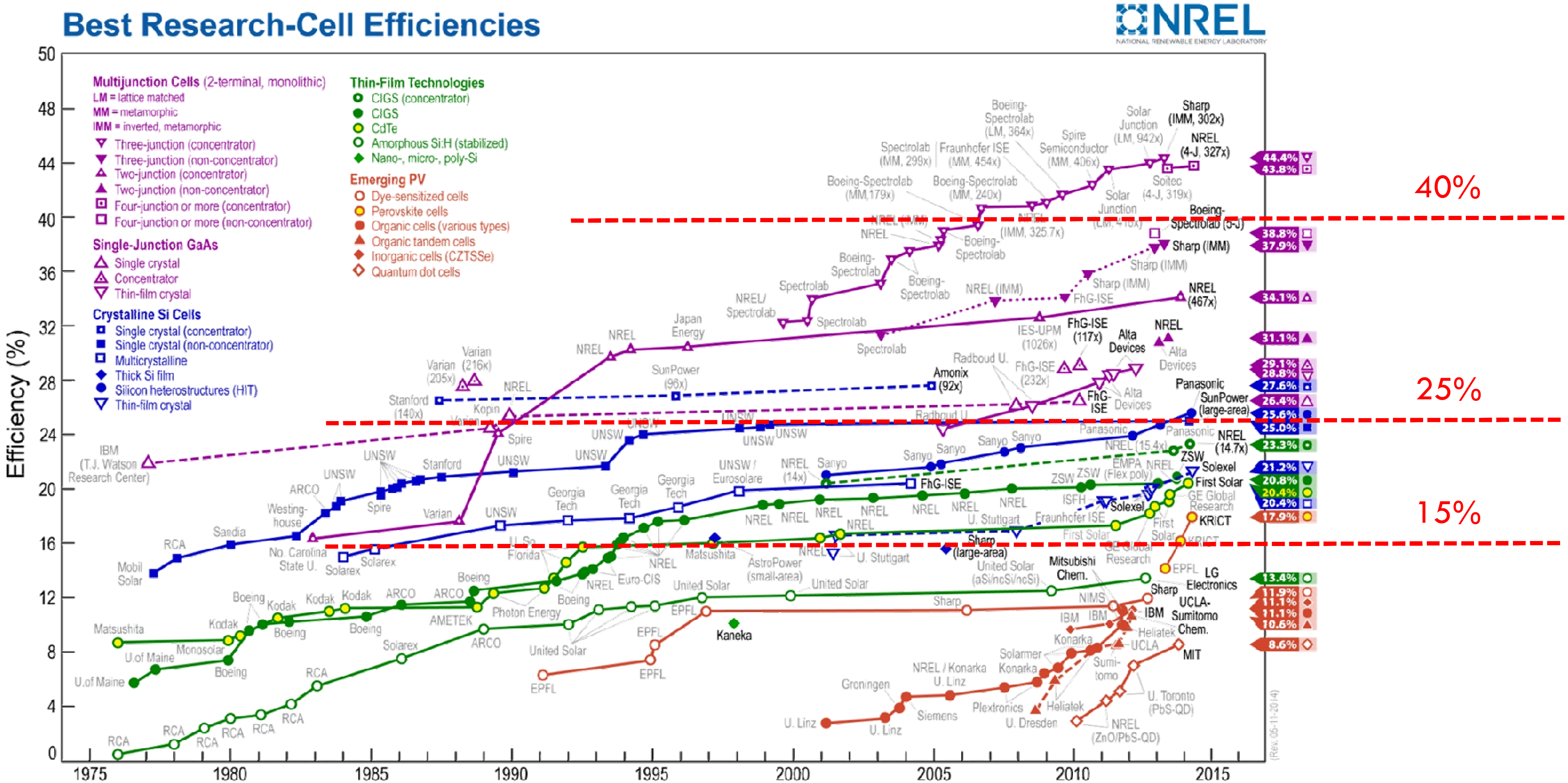
Bloomberg New Energy Finance, 2012

- In the early years, the demand exceeded the capacity of PV cell production (only the leftovers from electronics grade silicon were used).
- Asian giants appeared.
- Now only big companies can afford investments in production sites

What about efficiency?

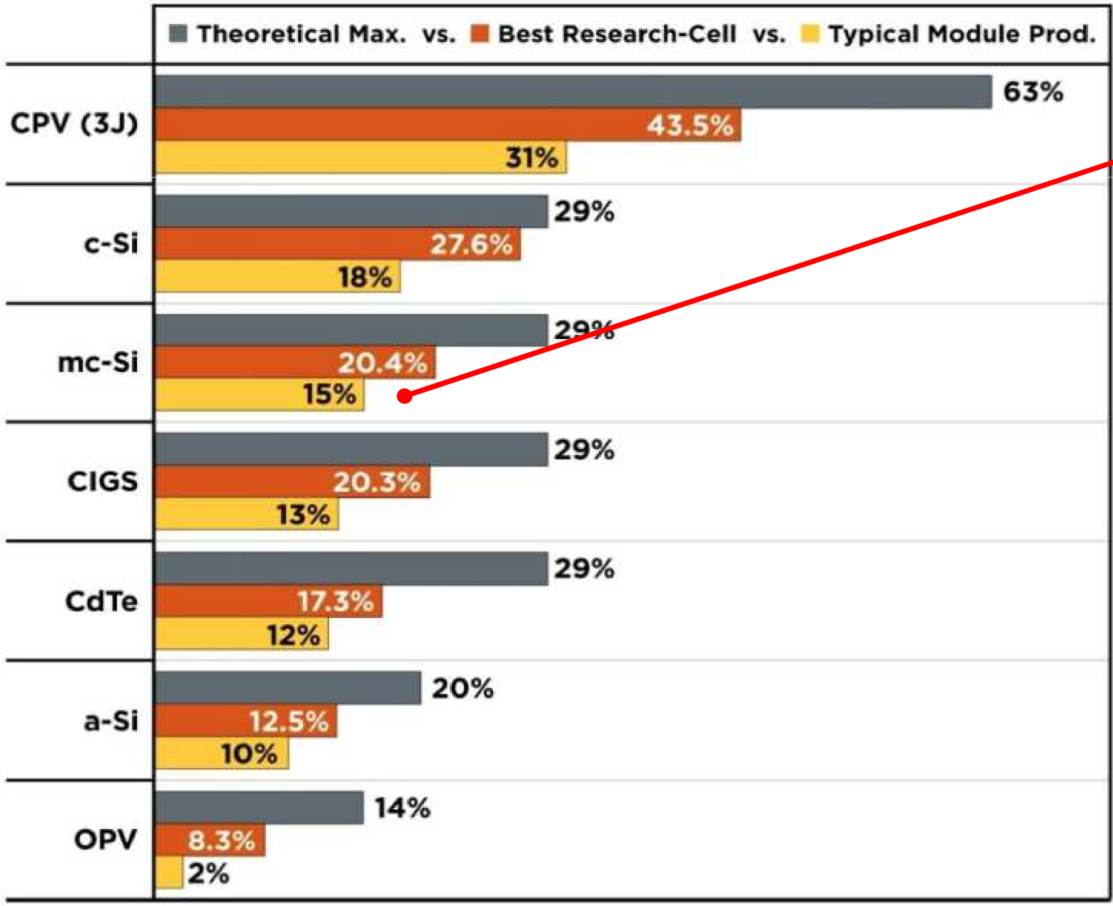
Cell efficiency evolution

Only multijuntion cells (CPV and space application) have achieved significant efficiency increases. Silicon and thin film technologies remain without any relevant changes lately



Module efficiency evolution

No major changes in the overall efficiency of the module. Significant improvements in mismatch, temperature losses, positive tolerance, etc. and quality control of materials used



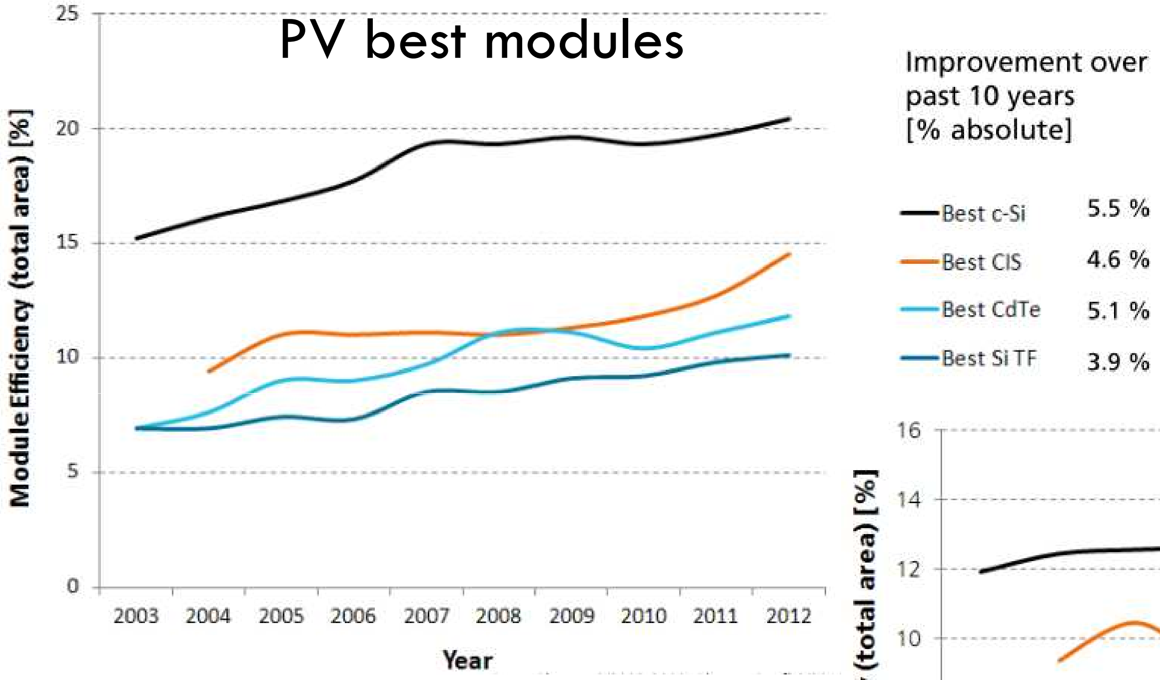
Best Seller 2013: 15,9% Yingli YL295P-35b

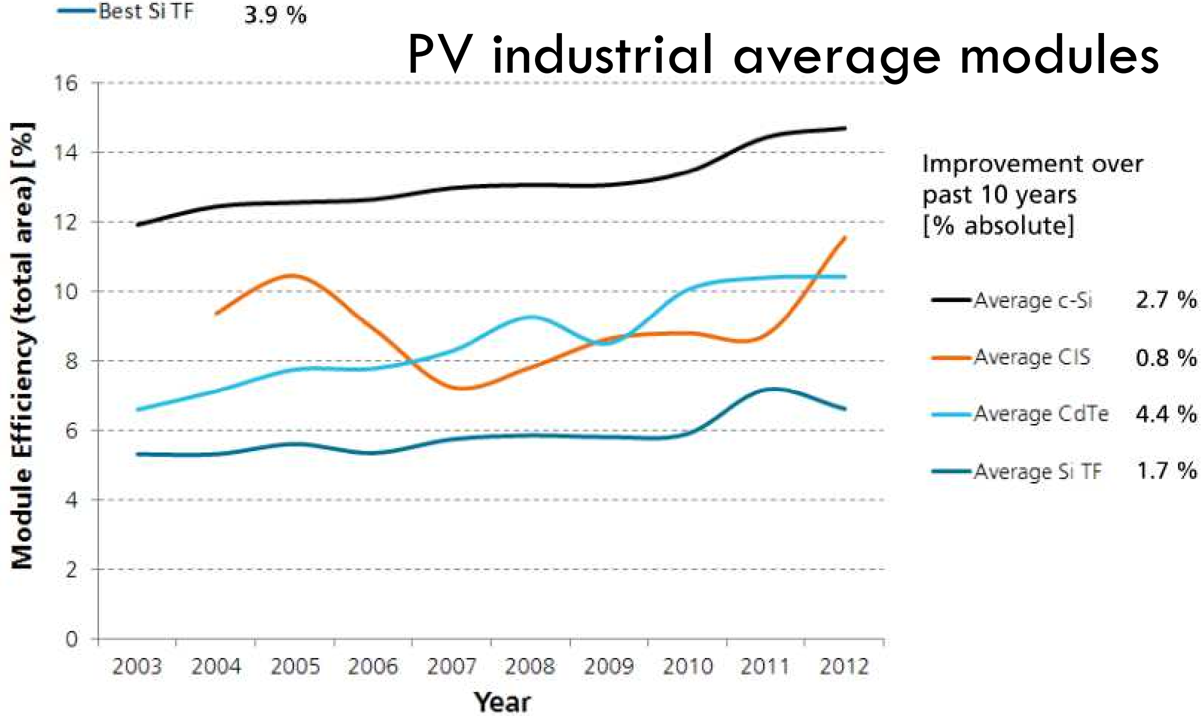
Photon Database2000 - 2013: conventional panel averaged (mono – multi c-Si) efficiency rate: 4% / 13 years (0.3%/year).

From 10 – 12% (2010) to 14 – 18% (2013)

NREL, 2013

Module efficiency evolution





Photom – ISE Fraunhofer, 2012

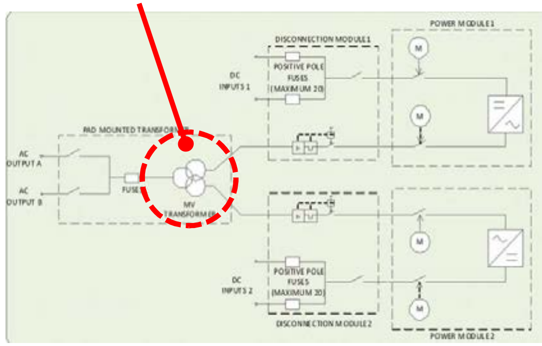
Inverter efficiency evolution

The most important indicators to characterize the advances in inverter technology are: costs, efficiency, losses and reliability & service (described by the Mean Time Between Failure or MTBF)

	1990	2009	2015
Price	1 Euro/W	0,3 Euro/W	0,2 Euro/W
Efficiency	90 %	96 - 98 %	97 - 99 %
Reliability, Service	MTBF: 0,1 million h	MTBF: 0,5 million h	MTBF: 1 million h
Additional Benefits		Backup functions & storages, power quality improvements, ancillary system services, ...	

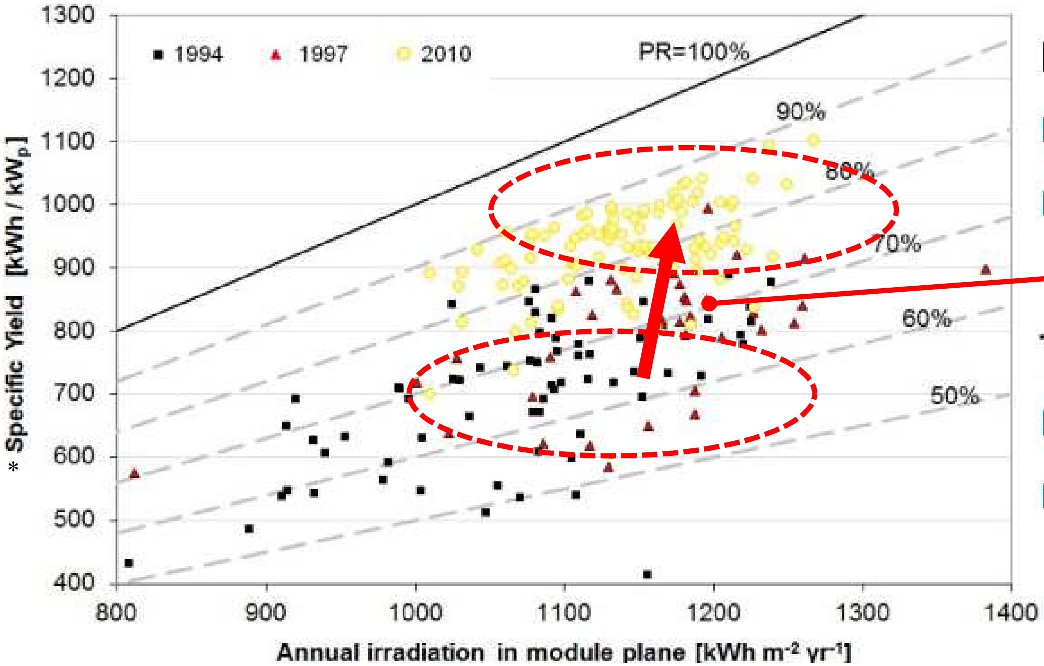
SMA, 2014

3 inverters in the same configuration are coming for large power plants



System efficiency evolution

Experience, know-how and best practices in engineering and design have improved the efficiency of systems. Critical equipment efficiency have been improved



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

ISE Fraunhofer, 2013

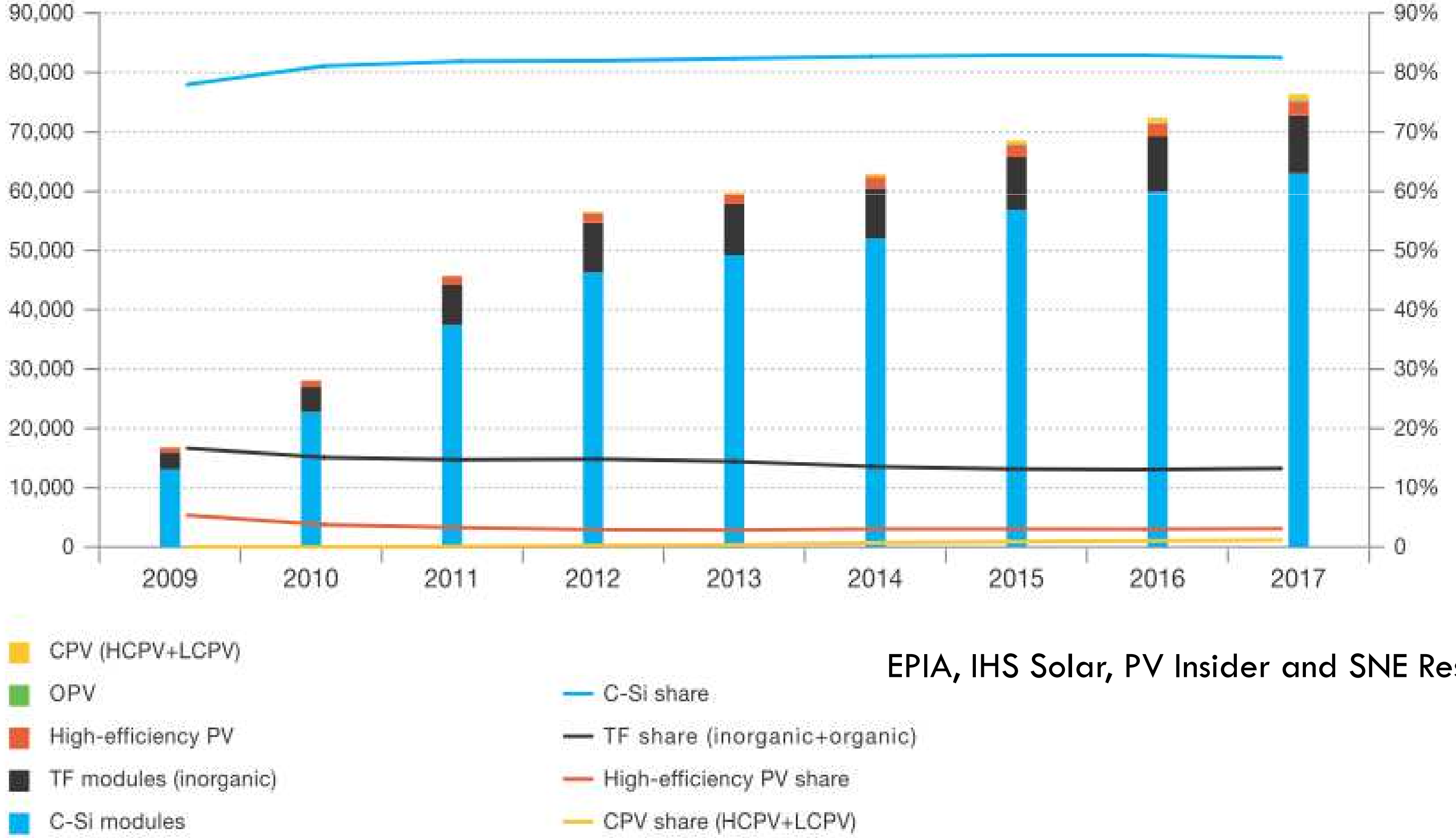
IES – UPM (Spain), with extensive experience in measuring performance of plants in operation has estimated a 15% system efficiency improvement in Spain, on average, from 2000 to now.

*Specific yield (kWh/kWp) is the total annual energy generated per kWp installed
*Performance Ratio (PR) quantifies the overall effect of losses on the rated output

Do you think you have good knowledge on the actual situation of the PV sector?

PV modules market

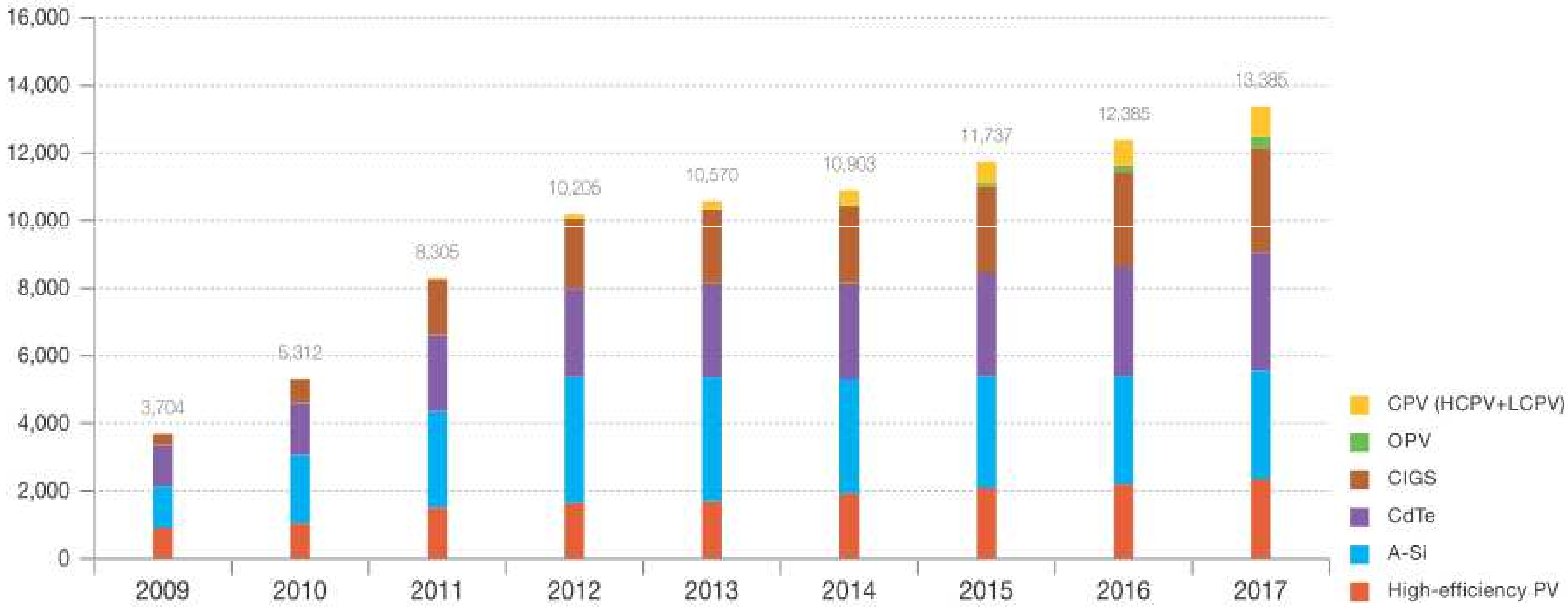
Silicon will continue dominating the market: low cost, high stability, low risk and demonstrated degradation



EPIA, IHS Solar, PV Insider and SNE Research, 2013

PV modules market

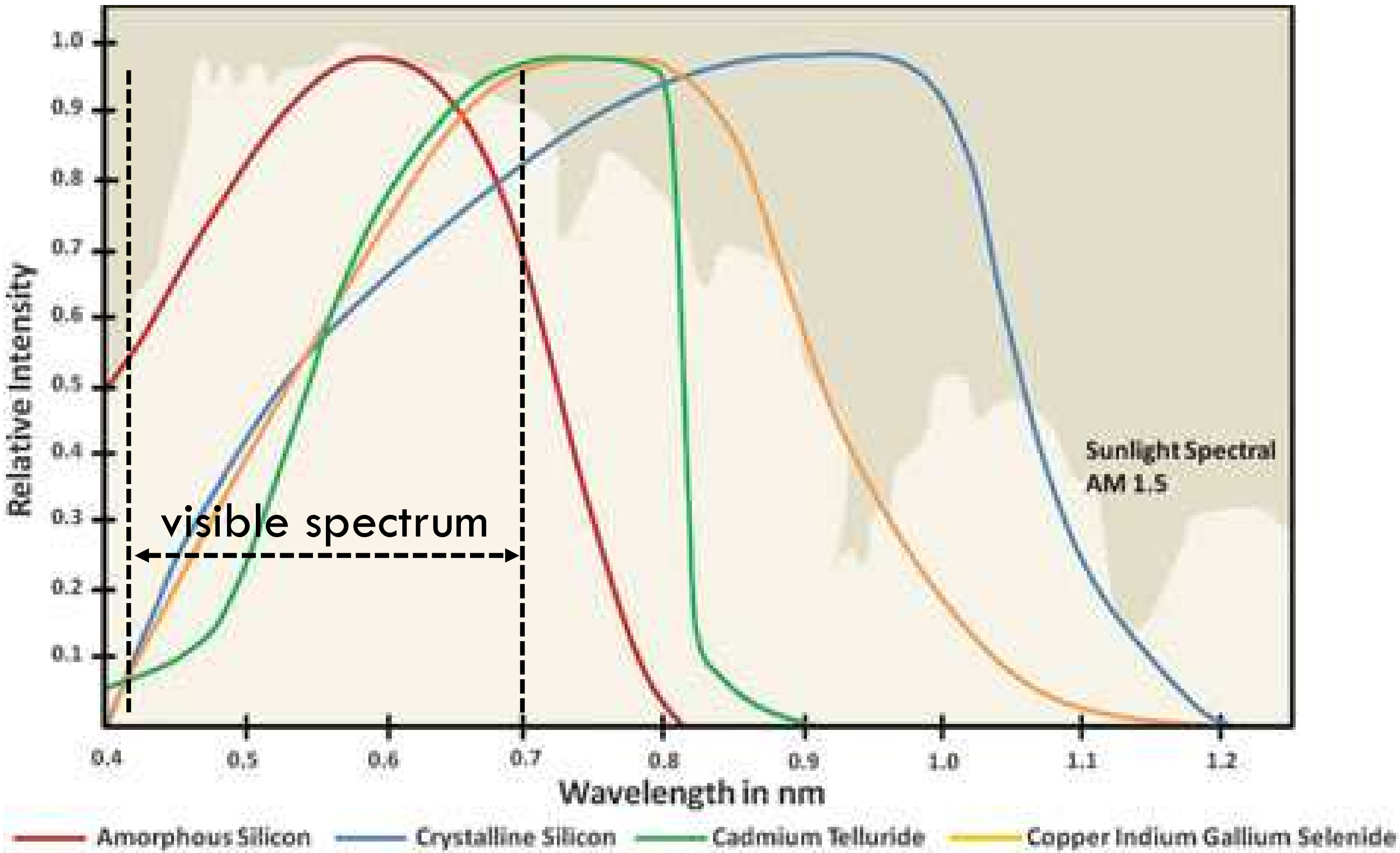
Non c-Si PV production capacity: Only CdTe and A-Si are relevant



EPIA, IHS Solar, PV Insider and SNE Research, 2013

PV modules market: semiconductors

Each PV semiconductor technology has a different efficiency, performance characteristics and cost

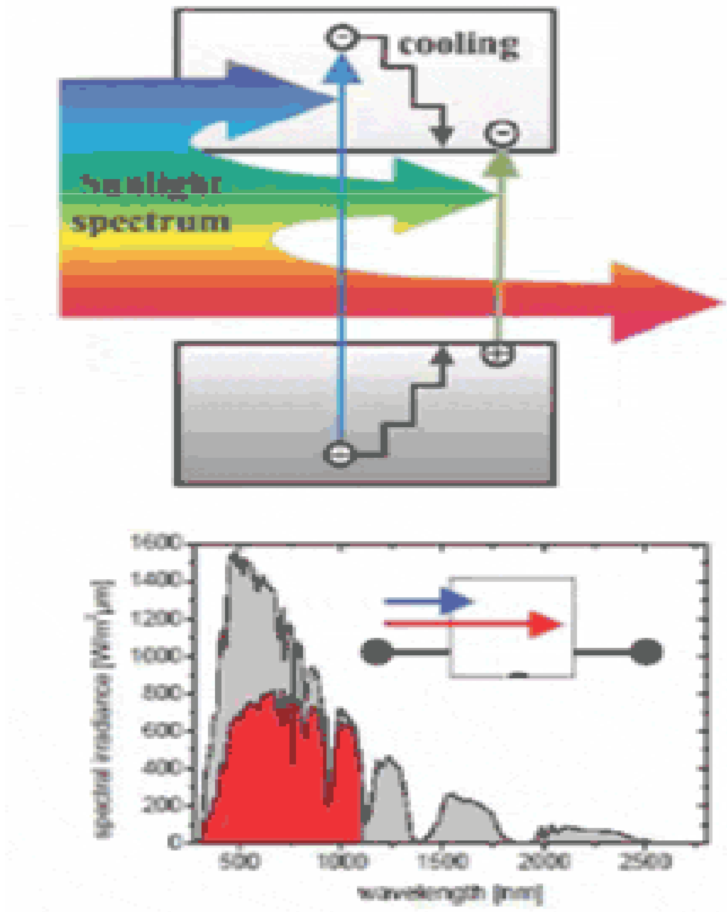


Source: ISET Kassel; Mulligan, 2004

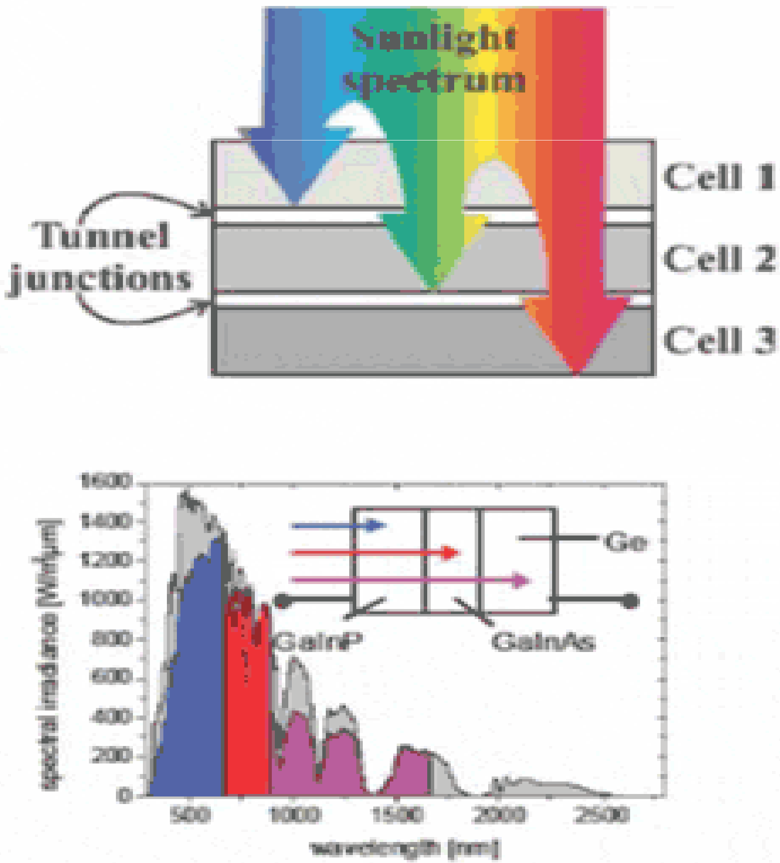
PV modules market: semiconductors

Why multifunction cells?: it covers more spectrum

Silicon



Multijunction



NREL, 2010

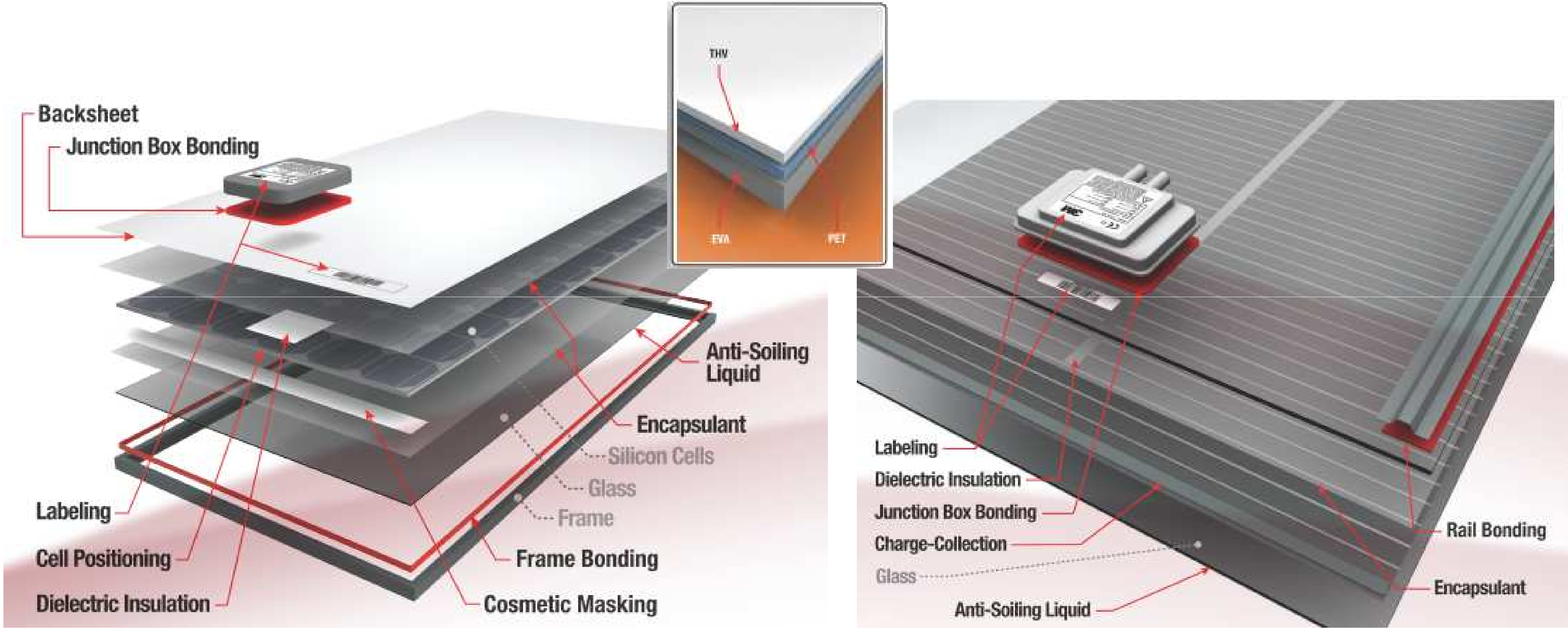
Commercial PV modules: silicon

Monocrystalline cell

Polycrystalline – polysilicon cell

PV panel

Commercial PV modules: silicon



3M, 2014

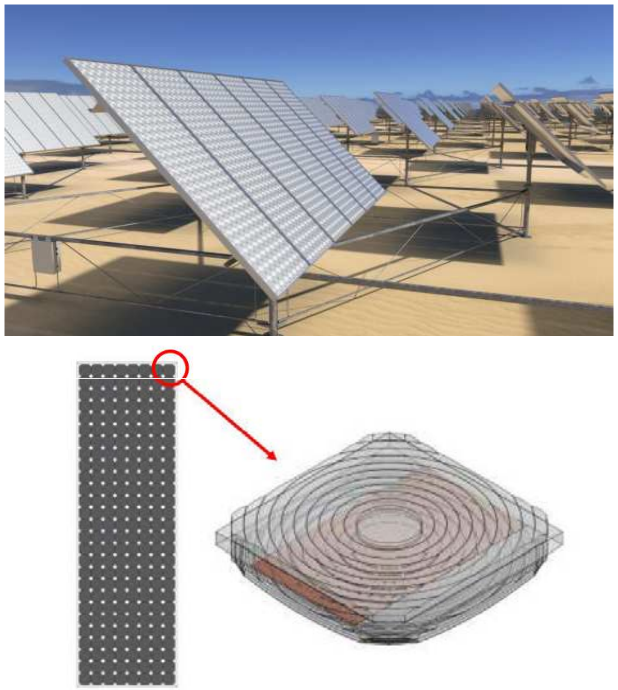
Commercial PV modules: thin film

Amorphous silicon
(T – Solar)

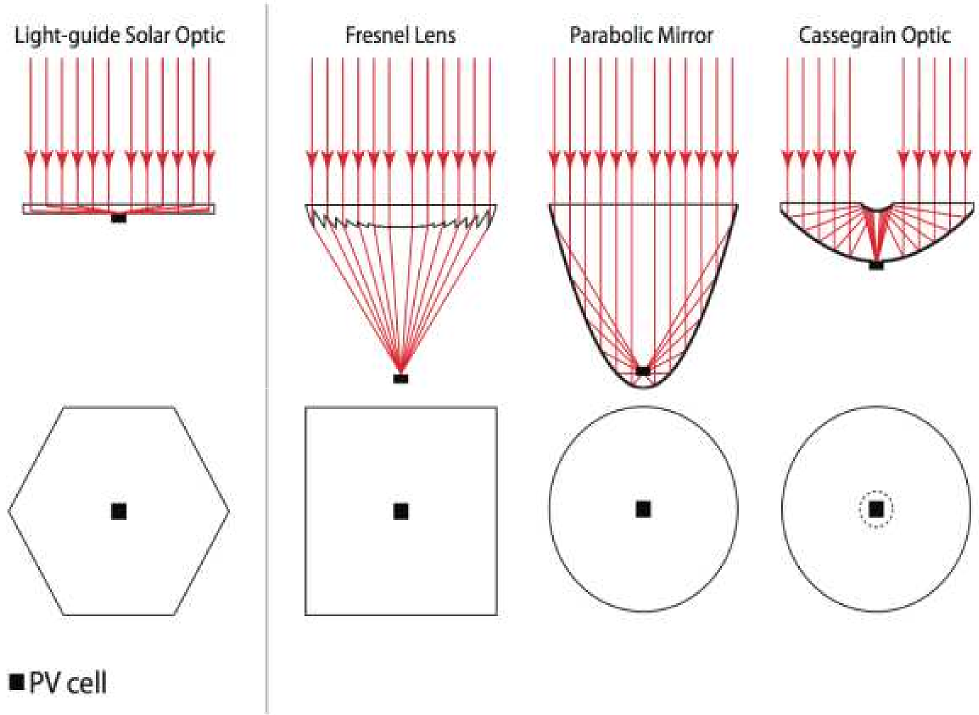
CdTe cadmium telluride
(First Solar)

CIGS copper indium gallium selenide (Solar Frontier)

Commercial PV modules: CPV



Morgan Solar, 2013



Eight to six years ago, there were more than 20 companies in the CPV industry. Nowadays, just a few companies are fighting to survive.

Soitec, 2013

Tracking- fixed

Nowadays, only single – axis tracker can be competitive against fixed structure

Mecasolar, 2011

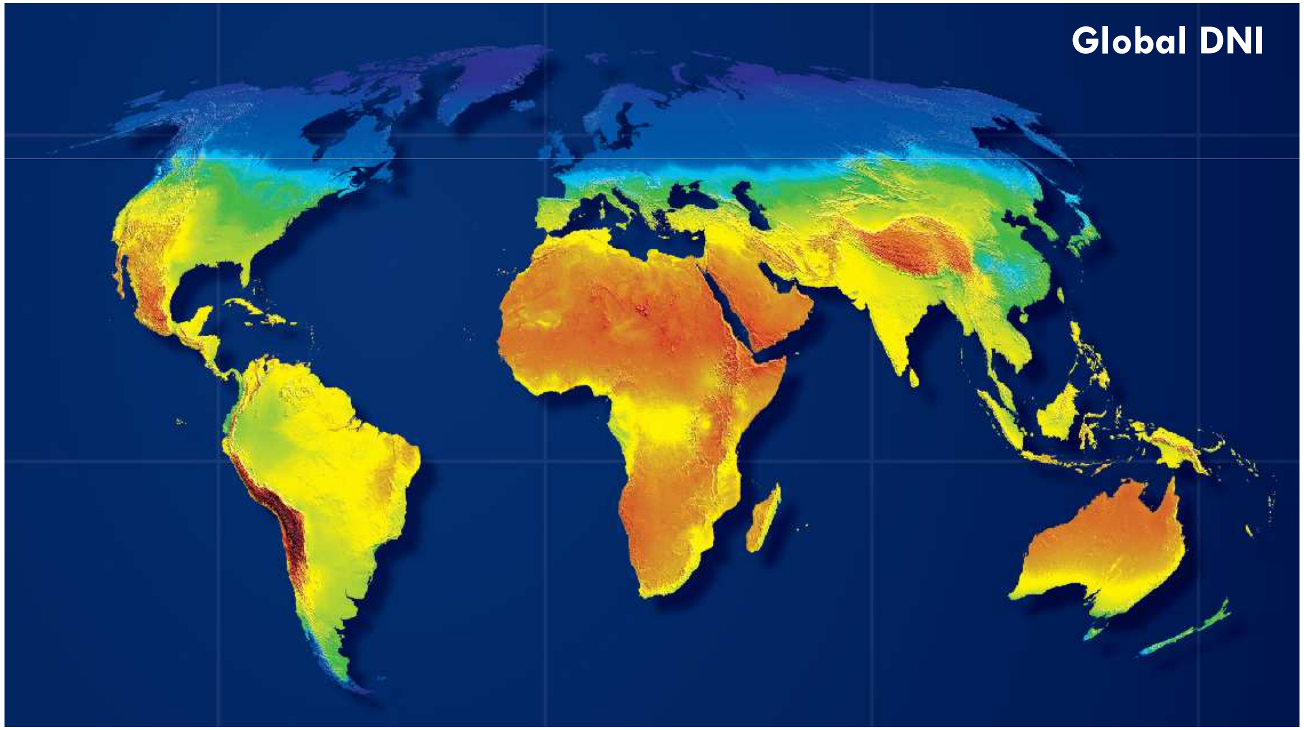
Acciona, 2010

Mecasolar, 2011

PV Hardware, 2013

Tracking- fixed

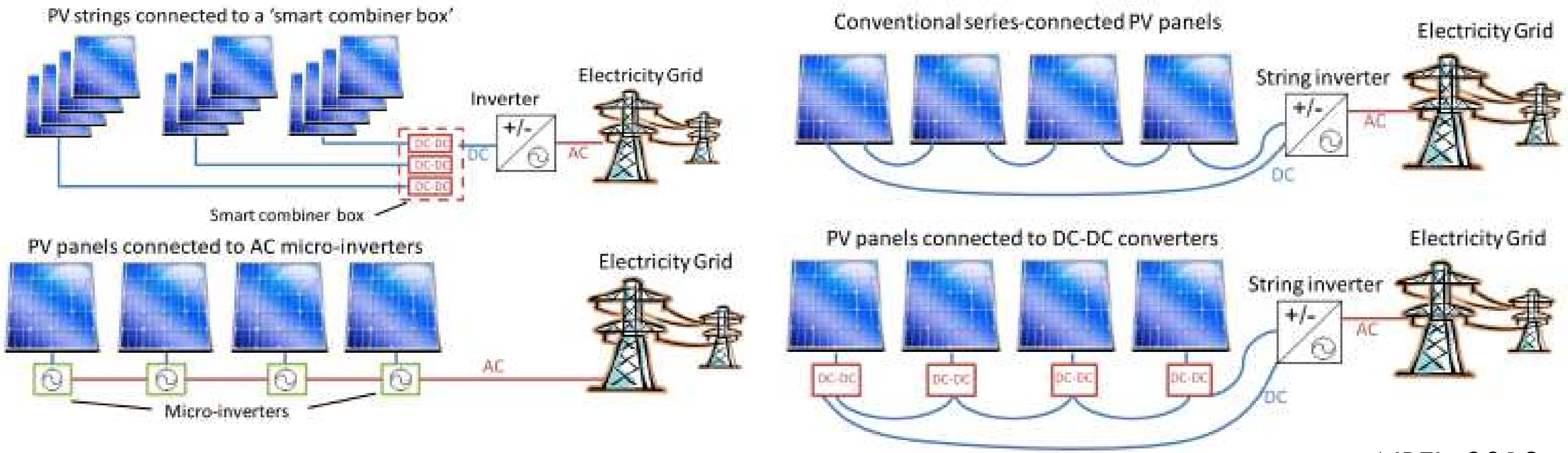
Solar tracking system increases the electricity production. This increment is achieved with high direct normal radiation values. On the other hand it will have a more expensive installation and operation cost



3Tier, 2014

System electrical

The most common configuration is the series one – connected PV panels and DC – AC inverter. DC – DC converter are used to improve the efficiency. Microinverter market is growing, specially for residential applications



NREL, 2013

Inverter market

Inverter efficiency for state-of-the art brand products stands at 98 % and higher

market share

above 36 kWp: 50%

IngeconSunLite, 2.5kW 2014

micro-inverters: 1%

Enphase Energy M250, 2014

up to 35 kWp : 49%

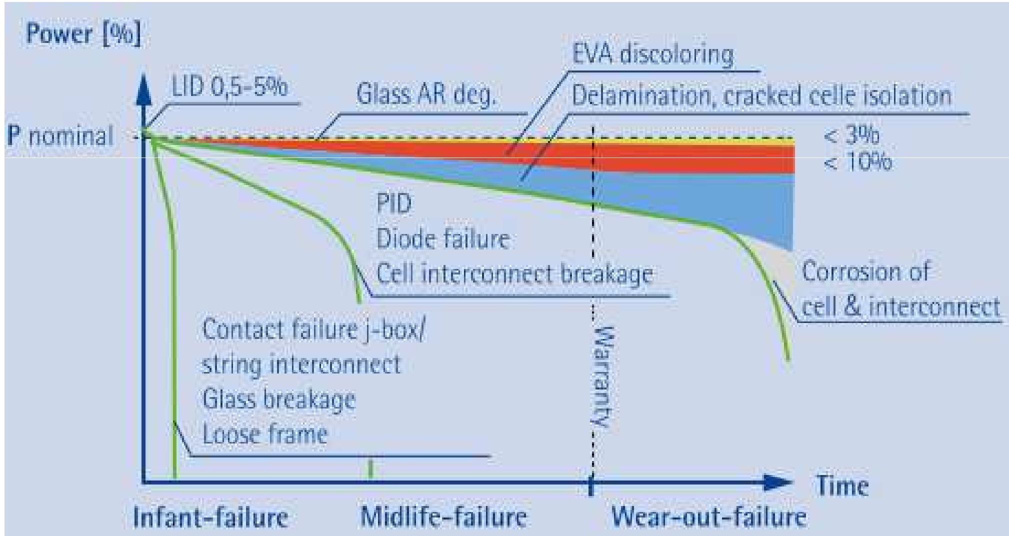
Ingecon Sun Power Staion 1.3kW 2014

Danfoss MLX 60, 2014

Life expectancy: 20, 30, how many years?

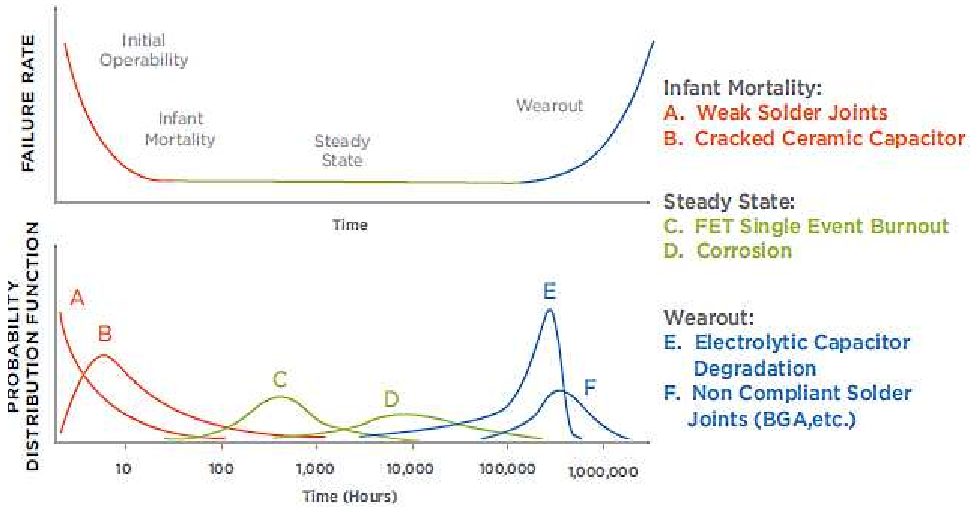
The most critical equipment is PV panels. Good manufacturing practice is critical: material quality, process control, etc

PV Panels Faiulre



IEA, 2013

Inverters Failure Rate



Solarbridgetech, 2013

Still good after 20 years: The LEE-TISO testing center for PV components at the University of Applied Sciences of Southern Switzerland installed Europe's first grid-connected PV plant, a 10kW roof, in May 1982. They analyzed the performance of the panels in 2002: 9% less than the initial rated peak output.

Standards

Standards and certifications are a key point in electrical systems. Especially in PV because the large percentage of the total cost of the system is equipment. Besides the performance guarantees are given by the panels and investors

International Organization for Standardization

INTERNATIONAL ELECTROTECHNICAL COMMISSION

American Society for Testing Materials

TESTS AND CERTIFICATIONS	
Standard tests	UL 1703, IEC 61215, IEC 61730
Quality tests	ISO 9001:2008, ISO 14001:2004
EHS Compliance	RoHS, OHSAS 18001:2007, lead-free, PV Cycle
Ammonia test	IEC 62716
Salt Spray test	IEC 61701 (passed maximum severity)
PID test	Potential-Induced Degradation free: 1000V [10]
Available listings	CEC, JET, KEMCO, MCS, FSEC, CSA, UL, TUV

SunPower E-Series , 2014

QUALIFICATIONS & CERTIFICATES

IEC 61215, IEC 61730, MCS, CE, ISO 9001:2008, ISO 14001:2004, BS OHSAS 18001:2007, PV Cycle, SA 8000

Yingli YP295P-35b , 2014

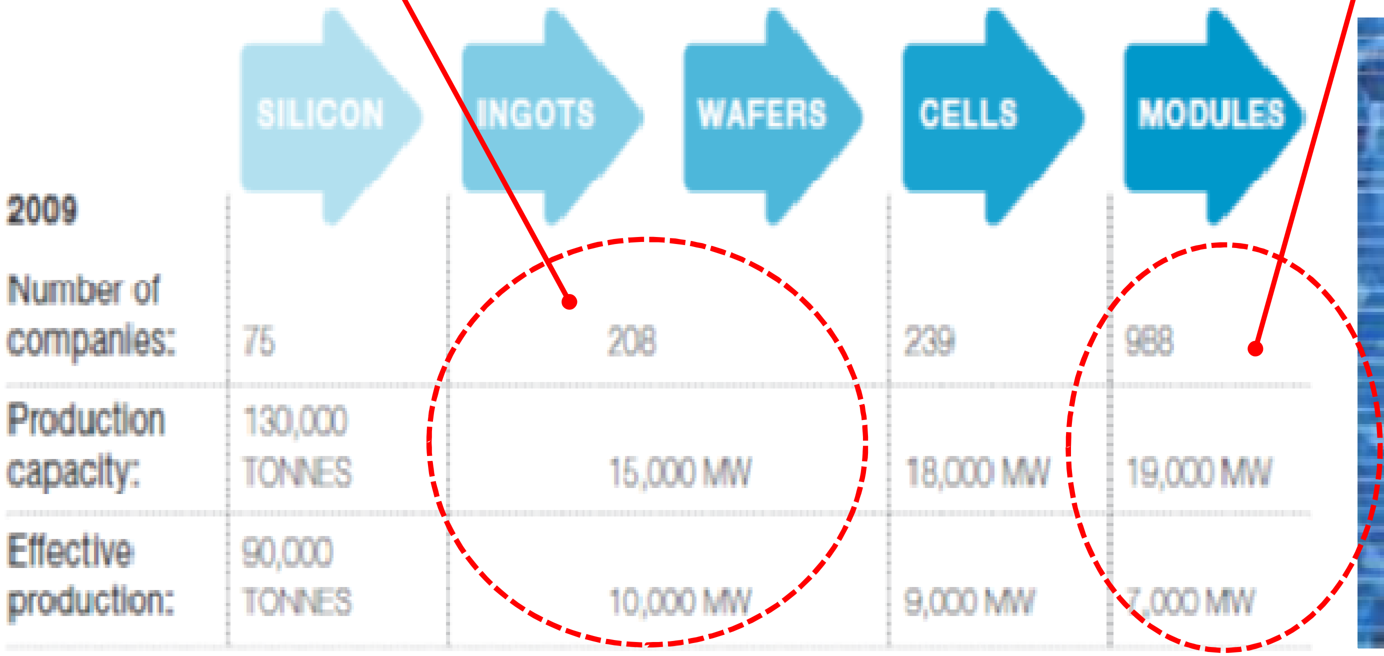
How does market growth?

Supply chain

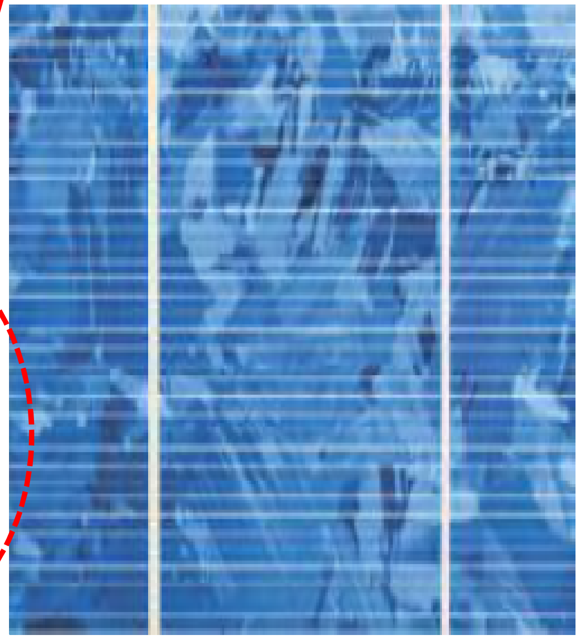
PV: only for big players. Capital and high level technology intensive sector. Asia (China and South Korea), Germany and USA are the leaders. Production capacity is continuously growing

2012: 48 GW global capacity (China 35 GW)

2014: 50 – 60 GW?



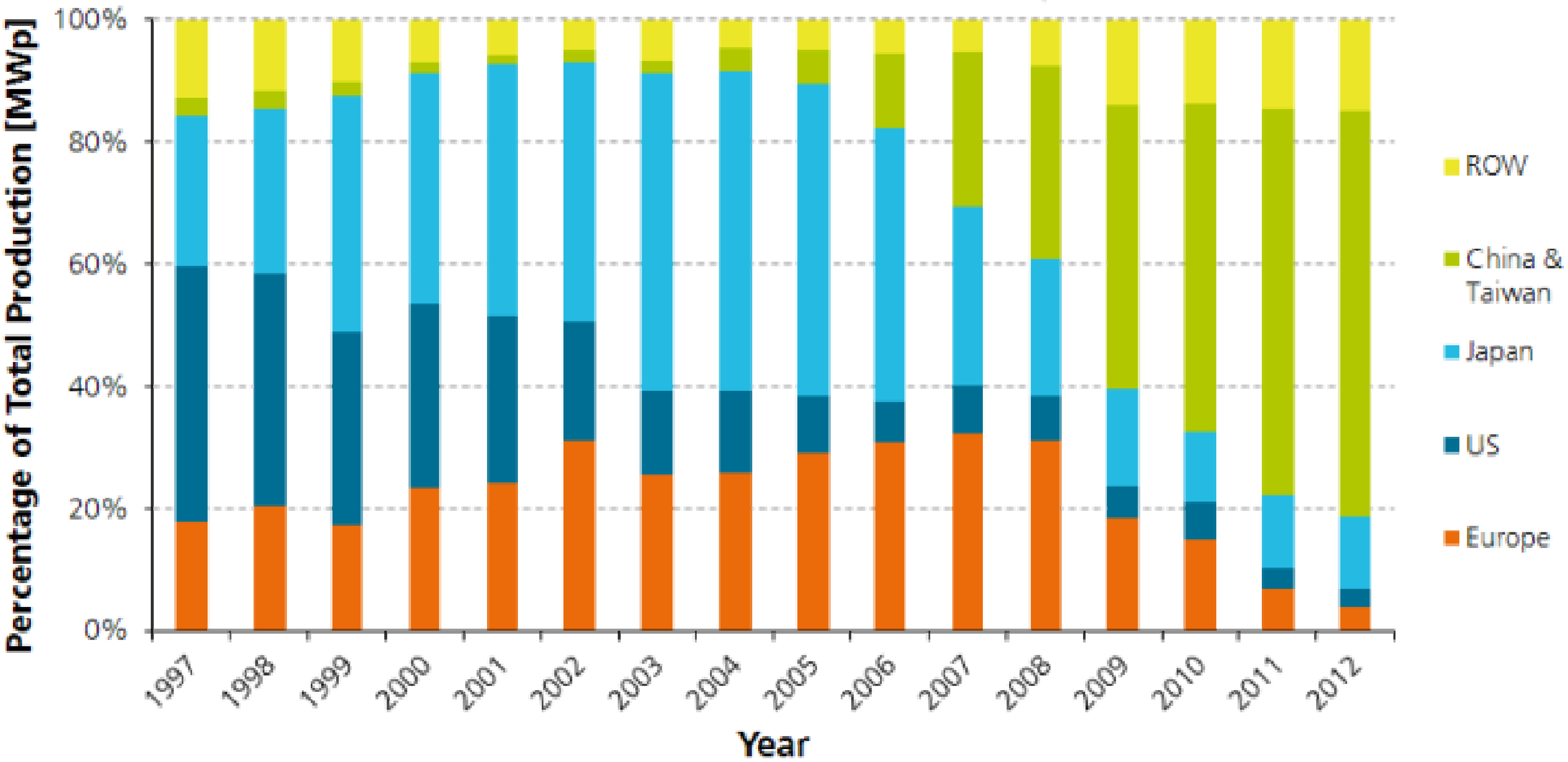
2009	SILICON	INGOTS	WAFERS	CELLS	MODULES
Number of companies:	75	208		239	988
Production capacity:	130,000 TONNES	15,000 MW		18,000 MW	19,000 MW
Effective production:	90,000 TONNES	10,000 MW		9,000 MW	7,000 MW



Photon, 2010

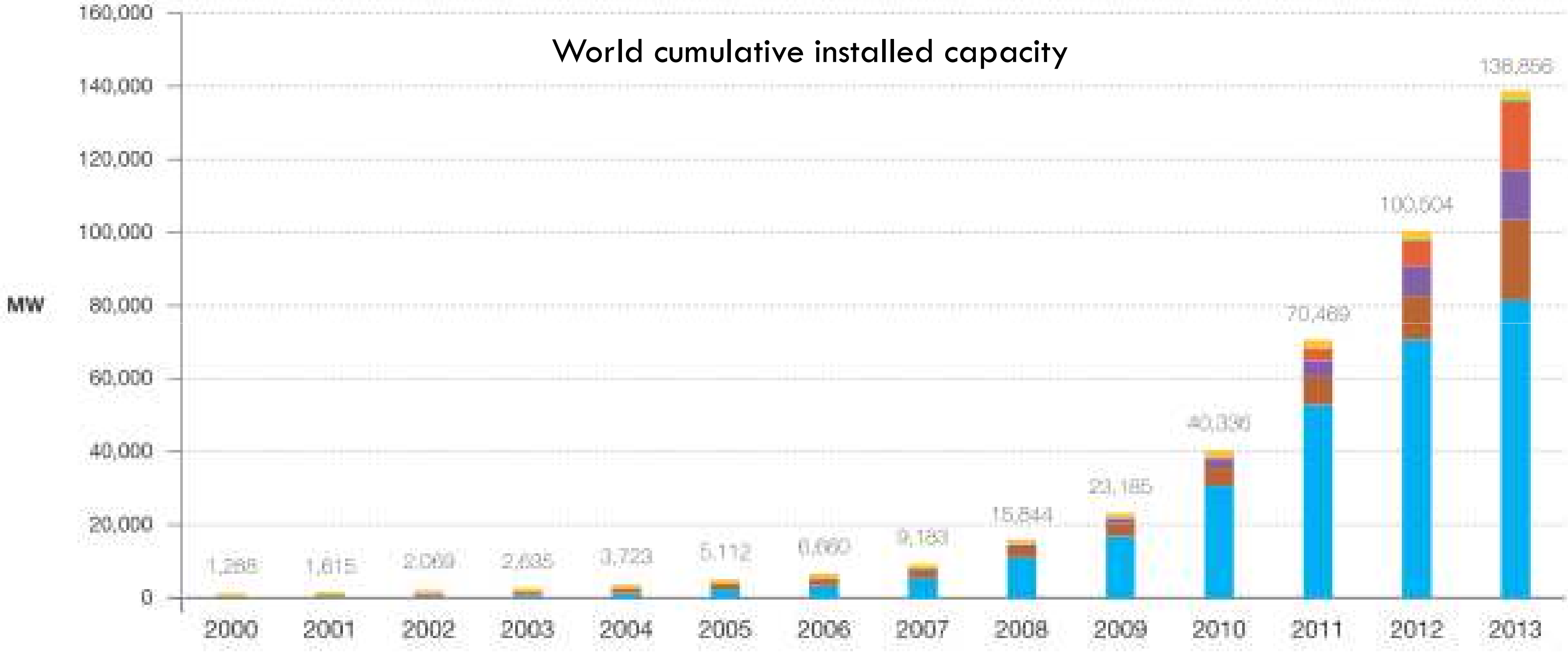
Supply chain

PV Cells/Modules Production by Region 1997-2012 (%of Total MWp Produced)



Navigant Consulting, 2012

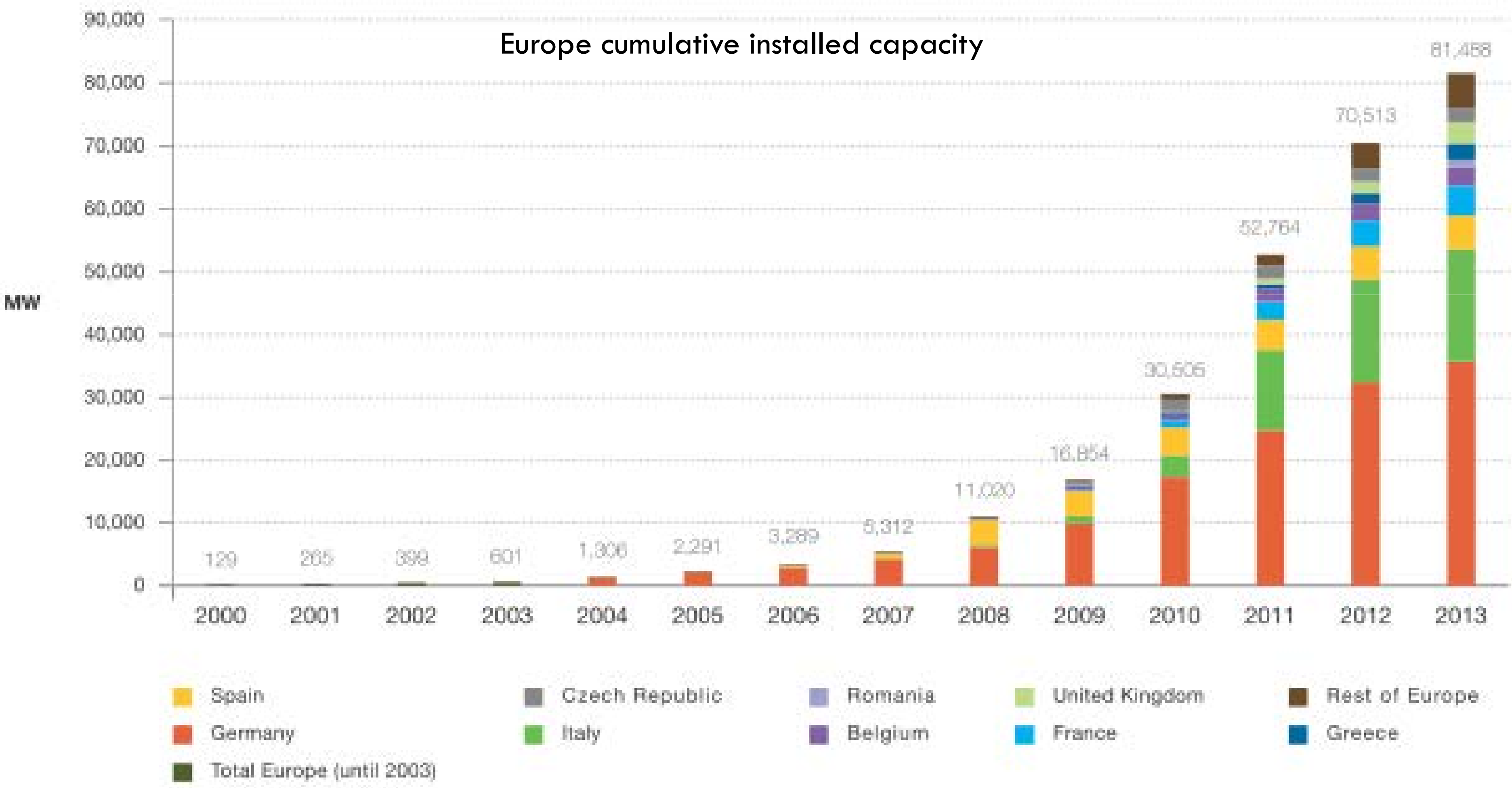
Market evolution



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
RoW	751	807	857	964	993	1,003	1,108	1,150	1,226	1,306	1,590	2,098	2,098	2,098
MEA	n/a	n/a	n/a	n/a	1	1	1	2	3	25	80	205	570	953
China	19	24	42	52	62	70	80	100	140	300	800	3,300	6,800	18,600
Americas	21	24	54	102	163	246	355	522	826	1,328	2,410	4,590	8,365	13,727
APAC	368	496	688	918	1,198	1,502	1,827	2,098	2,628	3,073	4,951	7,513	12,159	21,992
Europe	129	265	399	601	1,306	2,291	3,289	5,312	11,020	16,854	30,505	52,764	70,513	81,488
Total	1,288	1,615	2,069	2,636	3,723	5,112	6,660	9,183	15,844	23,185	40,336	70,469	100,504	138,856

EPIA2013

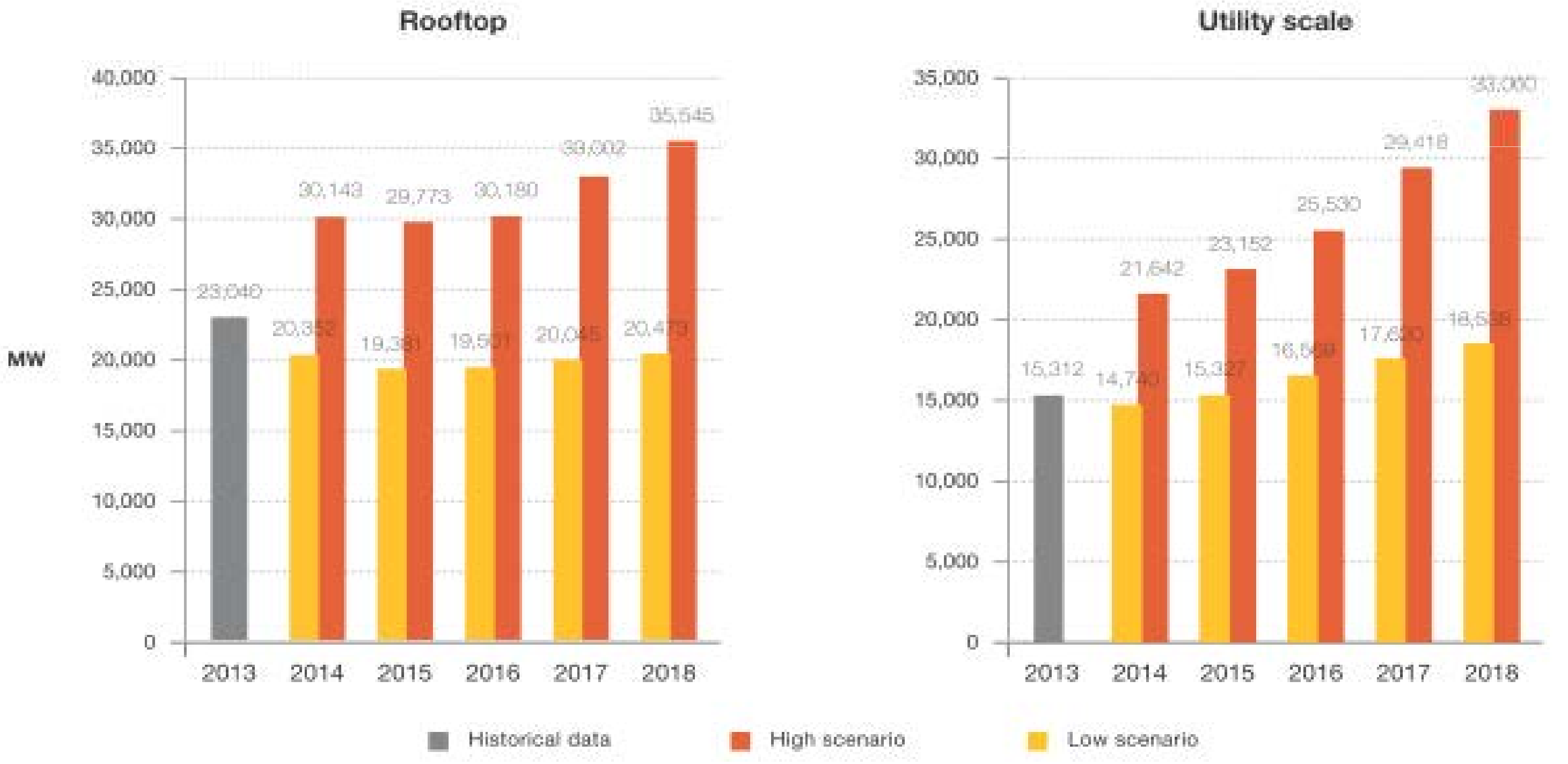
Market evolution



EPIA2013

Market evolution

The rooftop segment should experience stable growth from a global point of view. However, the world PV installation segmentation is changing: utility scale is the fastest growing segment



EPIA2013

Driving factors / barriers

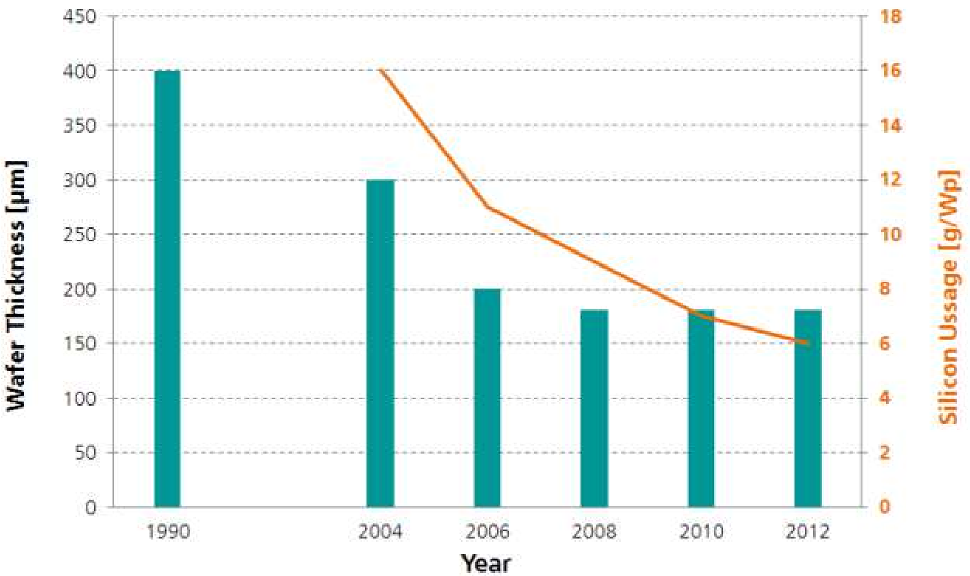
Driving factors	Barriers
People go green	Administrative procedures
Self - consumption	Grid connection
Smart Grid / Distributed generation	Utilities
Independent Power Producer	Forecast / Nowcasting
Easy to install	Solar resource (evaluation and availability)
Easy to operate (minimum cost)	Firm power capacity
Cost fall – grid parity	Capital intensive to install
Fossil prices have grown	New sector / technology / business model
Low risk: life expectancy over 30 years tested	Capacity building needed

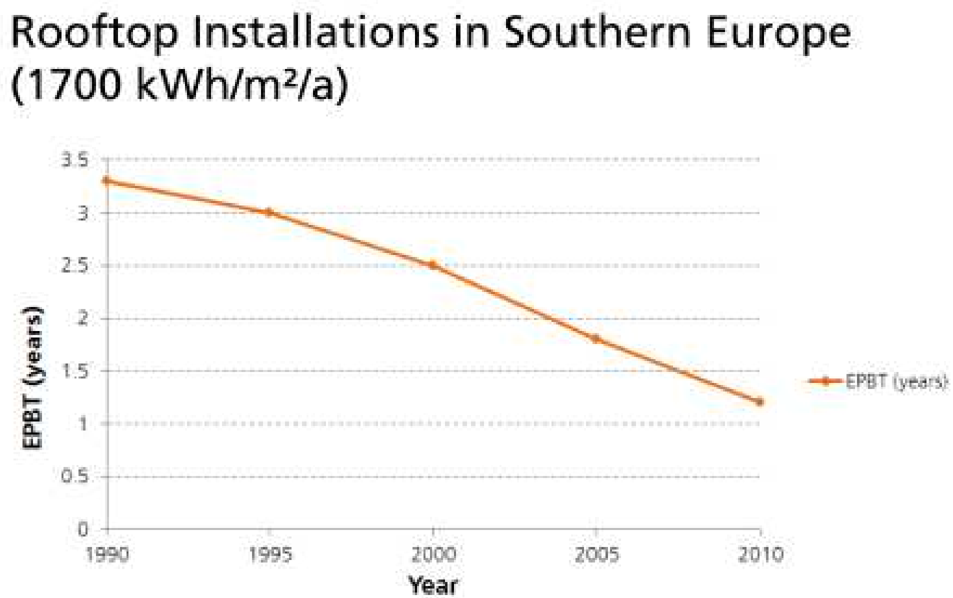
Is it sustainable?

Energy payback time (EPBT)

Depending on the type and location of the PV system, the EPBT currently 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

Less silicon, efficient process, high tech & automation and large scale factories

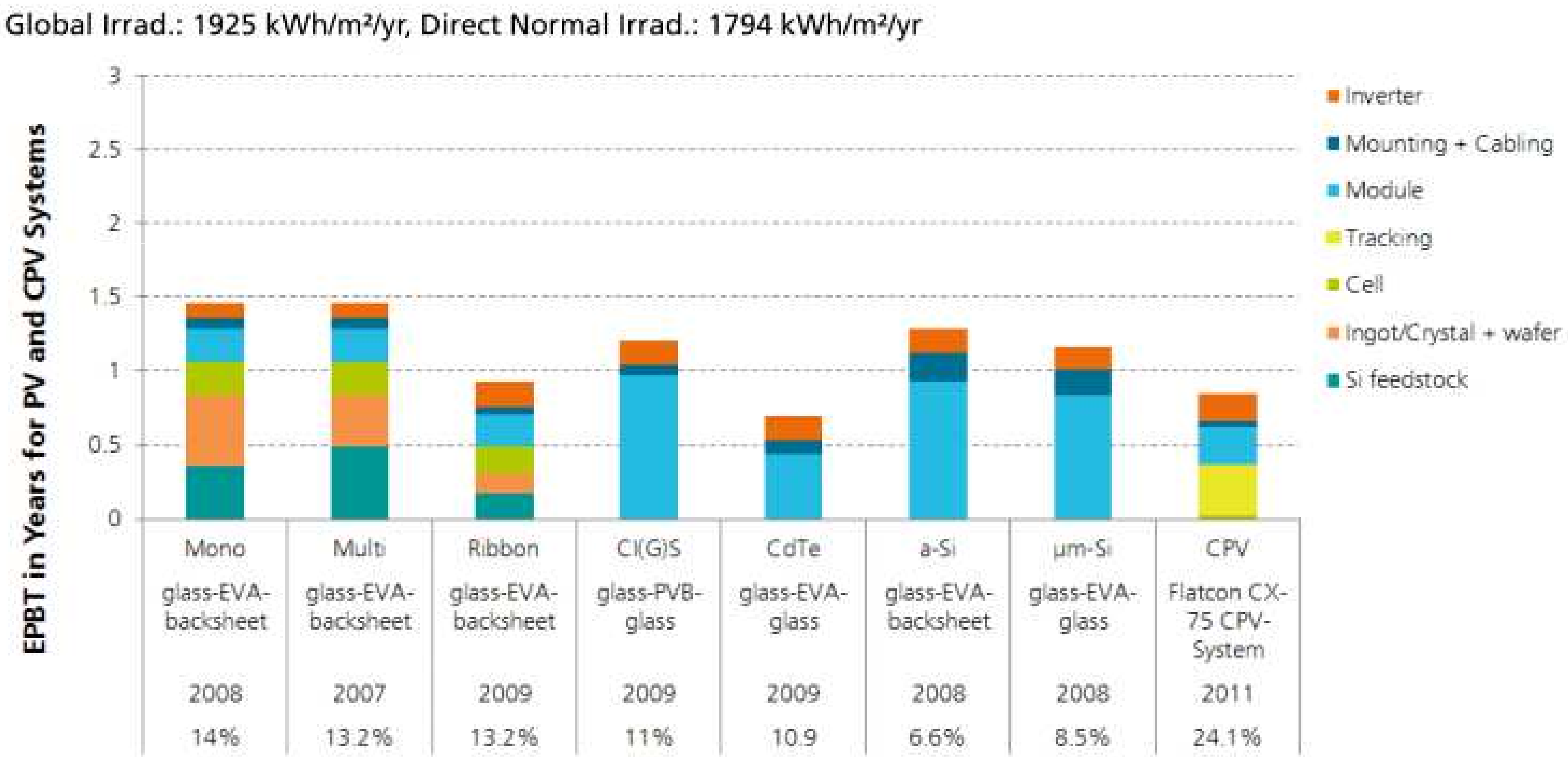




ISE-Fraunhofer, 2013

Energy payback time (EPBT)

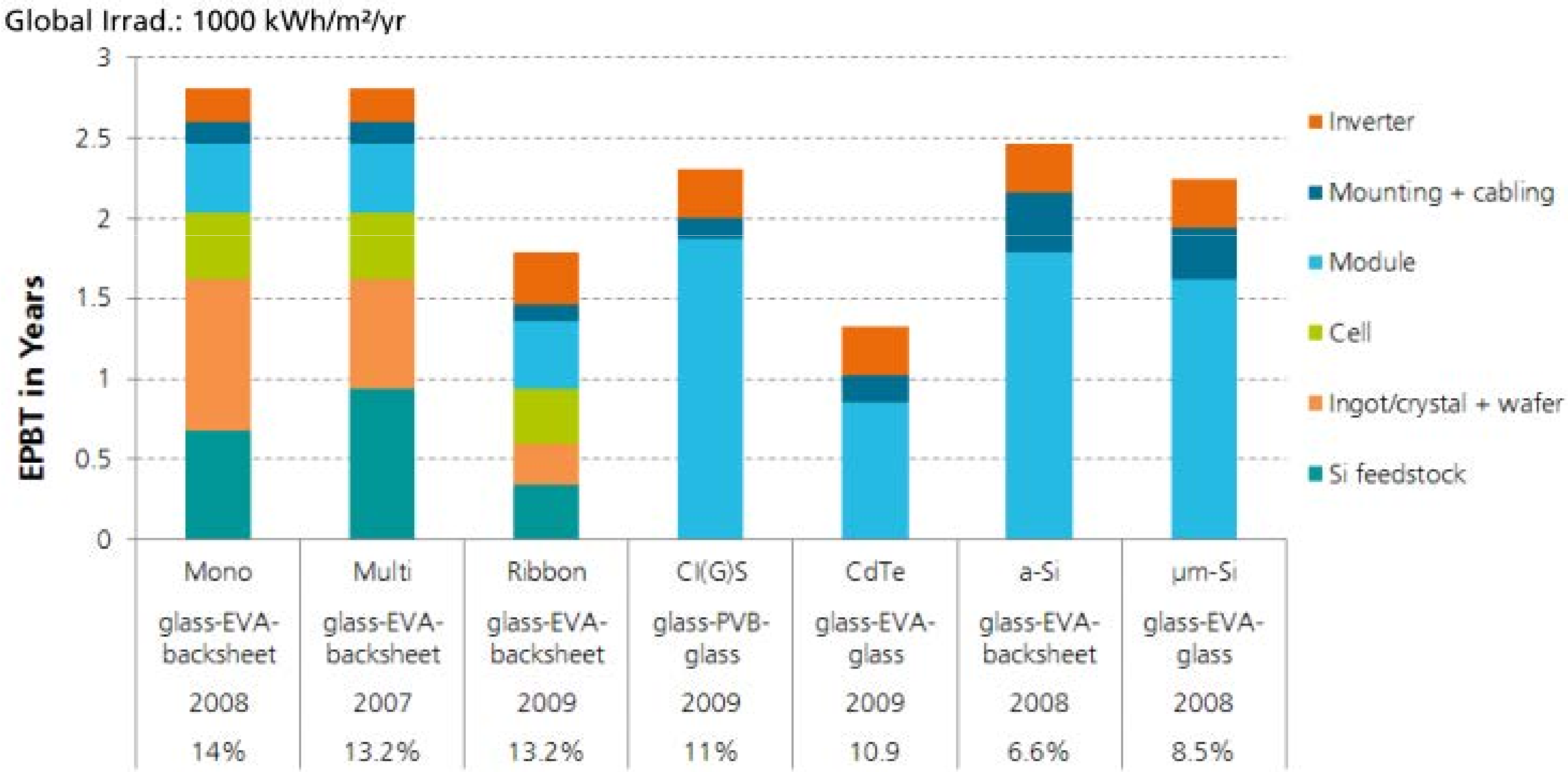
Ground system in South Europe



ISE-Fraunhofer, 2013

Energy payback time (EPBT)

Roof system in Germany



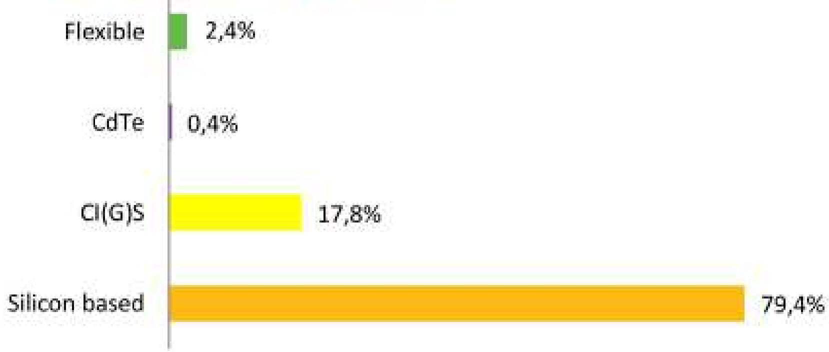
ISE-Fraunhofer, 2013

Recycling

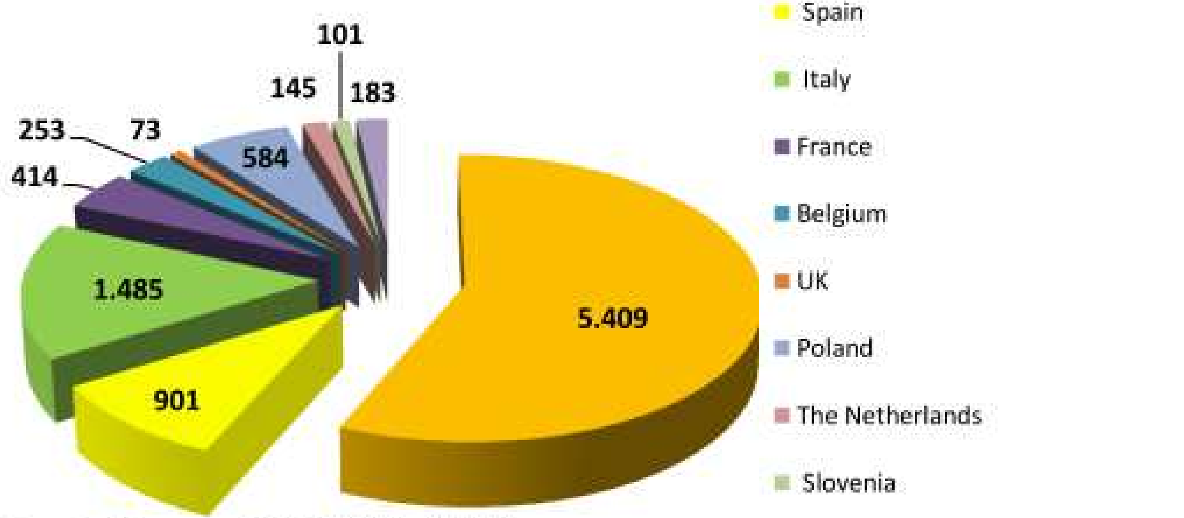
Solar industry has solutions for lifecycle management. PV CYCLE, as the leading take-back and recycling scheme in Europe, offers waste treatment and WEEE compliance solutions for all commercially available photovoltaic (PV) technologies

PV CYCLE

By technology, in %



Treated waste tonnes

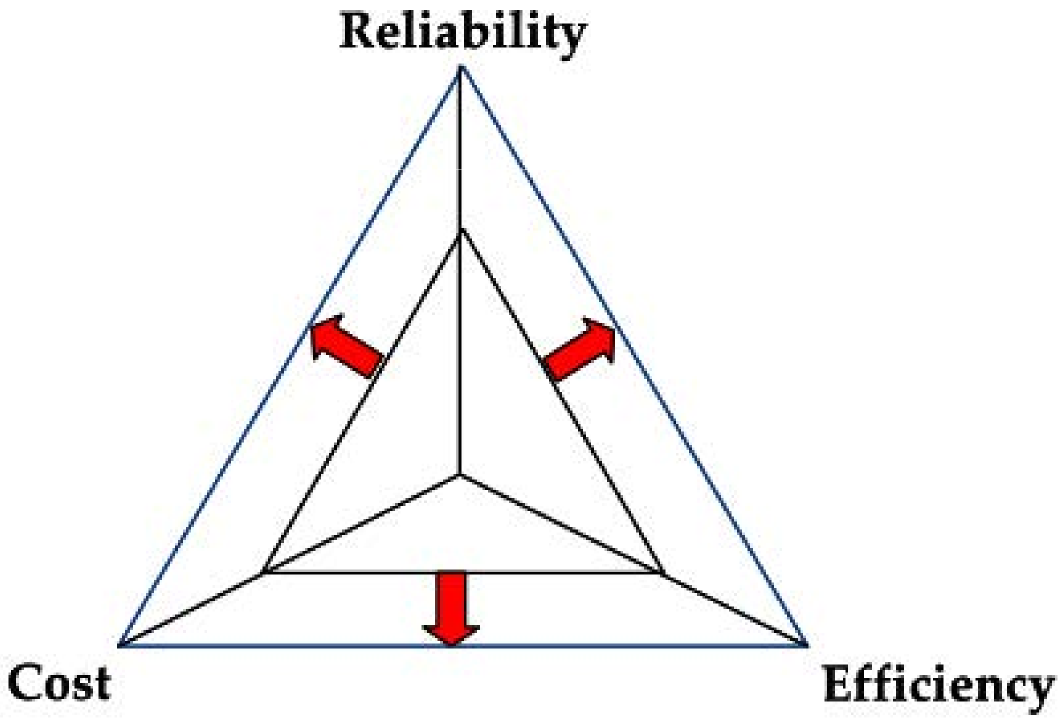


Total treated tonnes 2010-2014: 9.548t
Total treated tonnes in 05/2014 188t

Will grid parity change everything?
When?

PV economics

Reliability up to 98%, significant cost reduction and efficiency improved



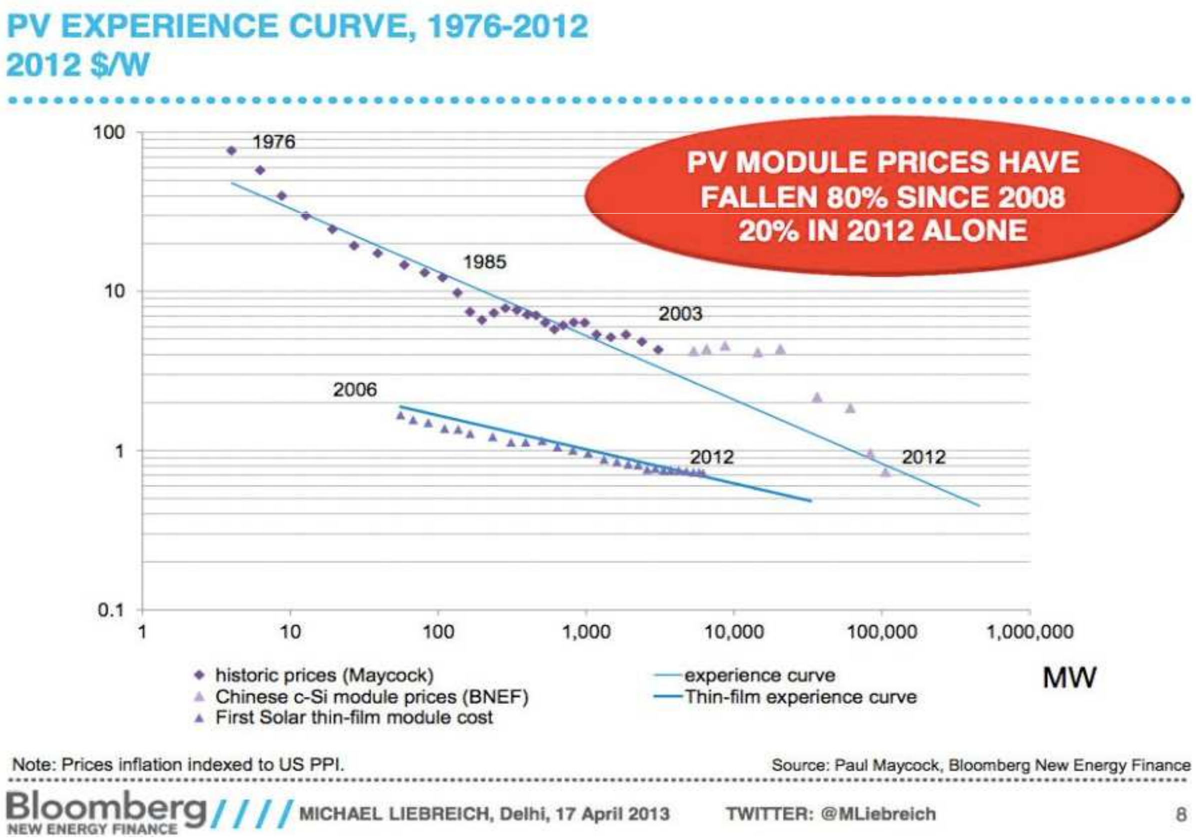
Levelized cost of energy (LCOE)

Levelized cost of energy depends on performance, system costs, and ongoing operations & maintenance over the lifetime of a system. All costs must be included: transmission grid, decommissioning, contamination, impact, social risk, supply & procurement, etc. *For all energies! please* 🙂

$$lcoe = \frac{Capex + \sum_{i=1}^{N} \frac{Opex_i}{(1+r)^i}}{\sum_{i=1}^{N} \frac{e_i}{(1+r)^i}} \quad ; \quad \begin{cases} r & \text{Discount rate} \\ e_i & \text{Specific energy yield [kWh/kWp]} \\ \mathrm{N} & \text{Lifetime [years]} \end{cases}$$

Cost evolution

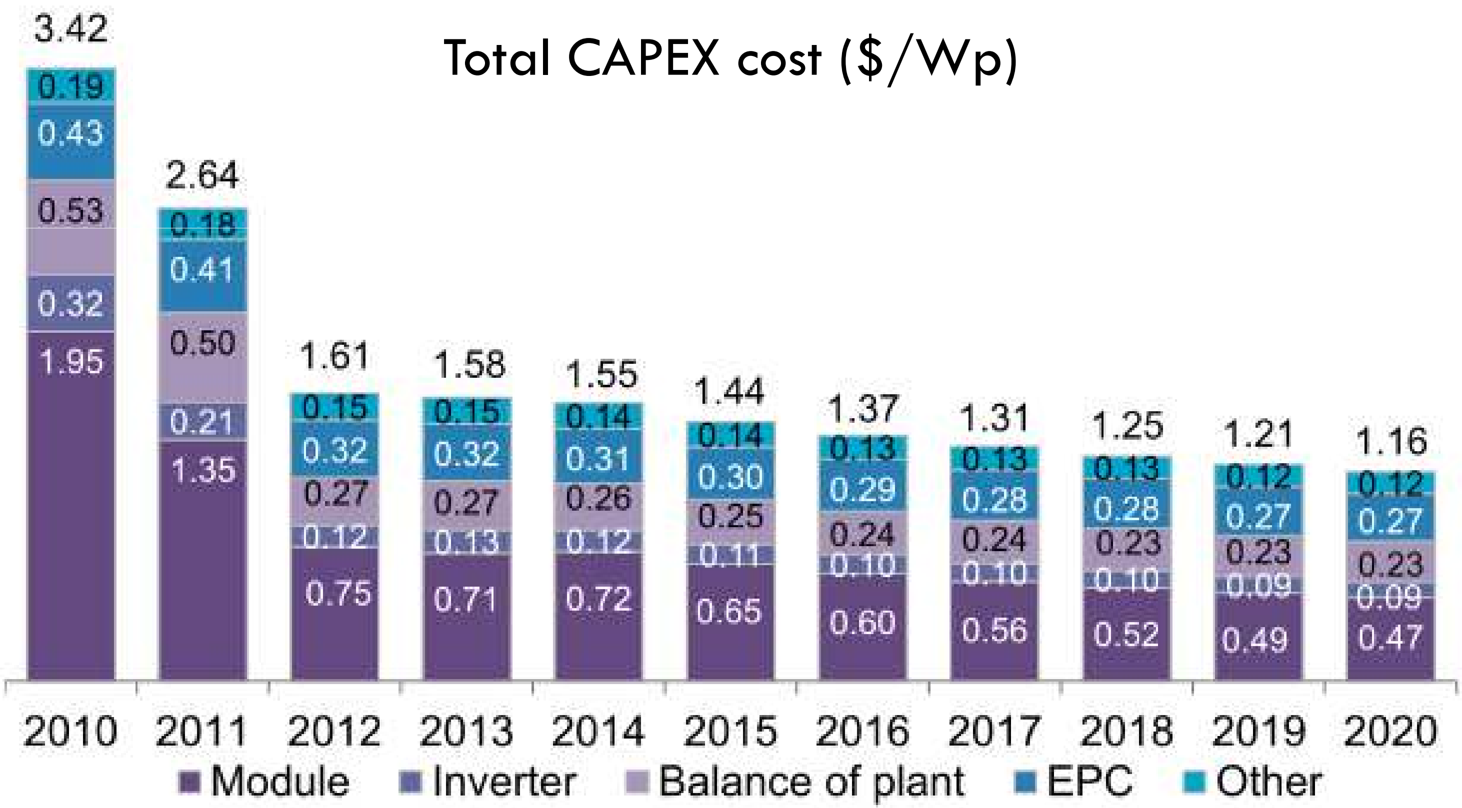
In 2012 the 1 $/W was overcome and silicon also exceeded thin film prices. Nowadays these prices remain stable, and are closer to 0.4 than 1$/W



Bloomber New Energy Finance, 2013

Cost evolution

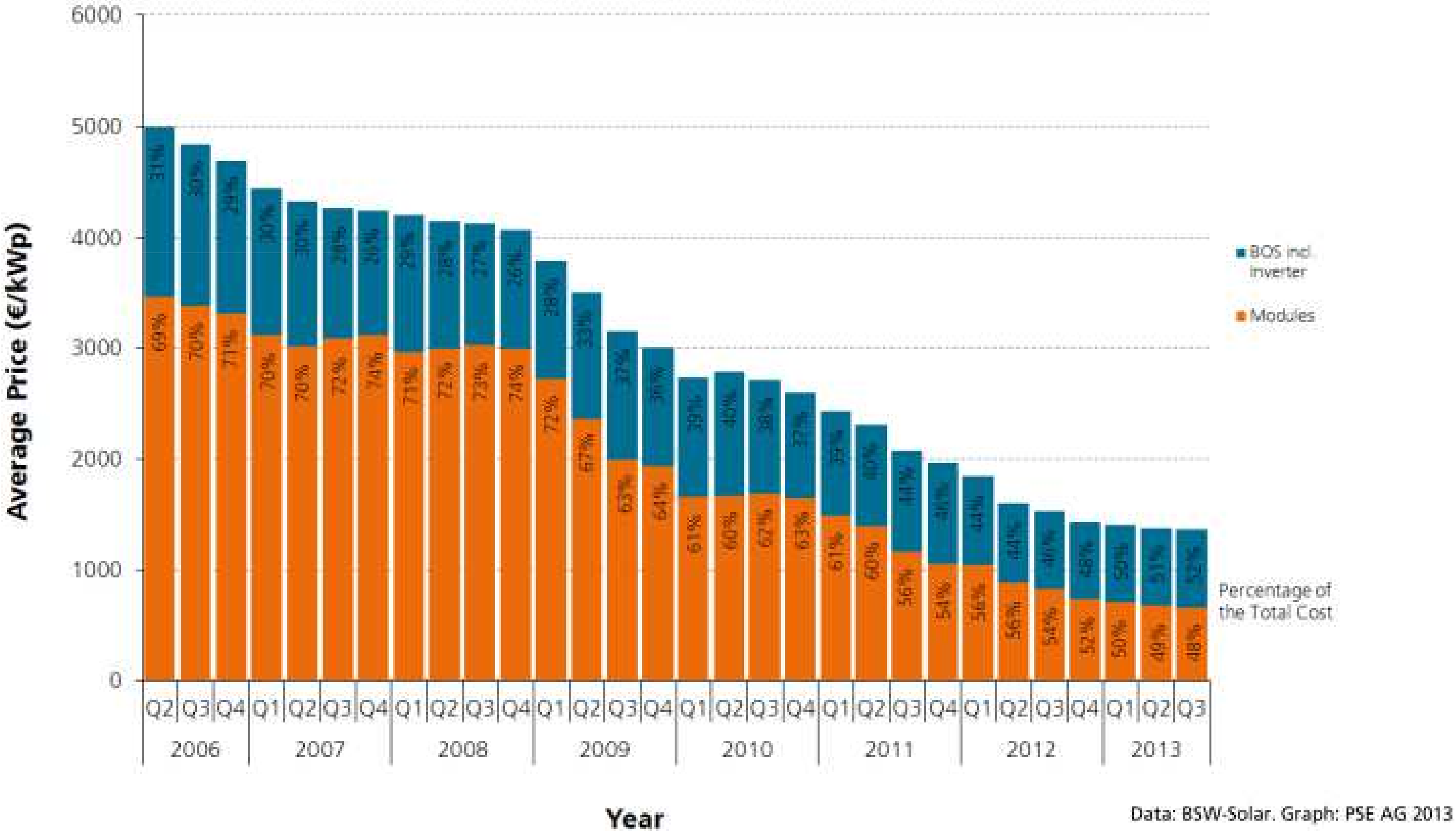
Forecasted cost for ground mounted PV projects in 2020 : the future is here



Bloomber New Energy Finance, 2013

Cost evolution

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



LCOE analysis

Deutsche Bank analysis: module prices around 65c$/W and systems cost around 1.5 – 2 $/W, 20 lifetime, 80% system performance, 0.7% degradation/year, discount rate = financing cost. **Realistic assumptions?**

Figure 5: North/South American Markets

	LCOE ($/KWh)	Cost of Electricity ($/KWh)	Type	Solar Vs Avoided Cost (5kW Panel)
North/South America				
Los Angeles, California, USA	$0.15	$0.20	Residential	-$0.05
California, USA	$0.16	$0.16	Residential	$0.01
Hawaii, USA	$0.14	$0.37	Residential	-$0.23
New Jersey, USA	$0.21	$0.16	Residential	$0.05
Ontario, Canada	$0.23	$0.12	Residential	$0.10
Mexico	$0.15	$0.09	Residential	$0.06
Mexico	$0.15	$0.13	Commercial	$0.02
Mexico	$0.15	$0.10	Industrial	$0.05
Chile	$0.15	$0.25	Residential	-$0.10
Argentina (unsubsidized)	$0.15	$0.14	Residential	$0.02
Argentina (subsidized)	$0.15	$0.09	Residential	$0.06

In blue grid - parity

Source: DB, BLS, Ontario Energy Board, Mexican Ministry of Energy, Chile Energy Group, Argentinean Secretary of Energy, NASA

Deutsche Bank, 2013

LCOE analysis

Figure 6: Asia Markets

	LCOE ($/KWh)	Cost of Electricity ($/KWh)	Type	Solar Vs Avoided Cost (5kW Panel)
Asia				
Japan	$0.18	$0.29	Residential	-$0.11
China	$0.18	$0.08	Residential	$0.10
China	$0.18	$0.11	Industrial	$0.07
India	$0.14	$0.09	Wholesale	$0.05
Malaysia	$0.16	$0.09	Commercial	$0.07
Malaysia	$0.16	$0.08	Industrial	$0.08
Thailand	$0.15	$0.12	Residential	$0.03
South Korea	$0.16	$0.19	Residential	-$0.03
South Korea	$0.16	$0.10	Wholesale	$0.07
Australia	$0.15	$0.16	Residential	-$0.01

Source: Deutsche Bank, Tepco, Chinese Economic Observer, Beijing International, Indian Central Electricity Regulatory Commission, Australia Power and Gas, NASA

Deutsche Bank, 2013

LCOE analysis

Figure 7: Middle East, Africa, Europe

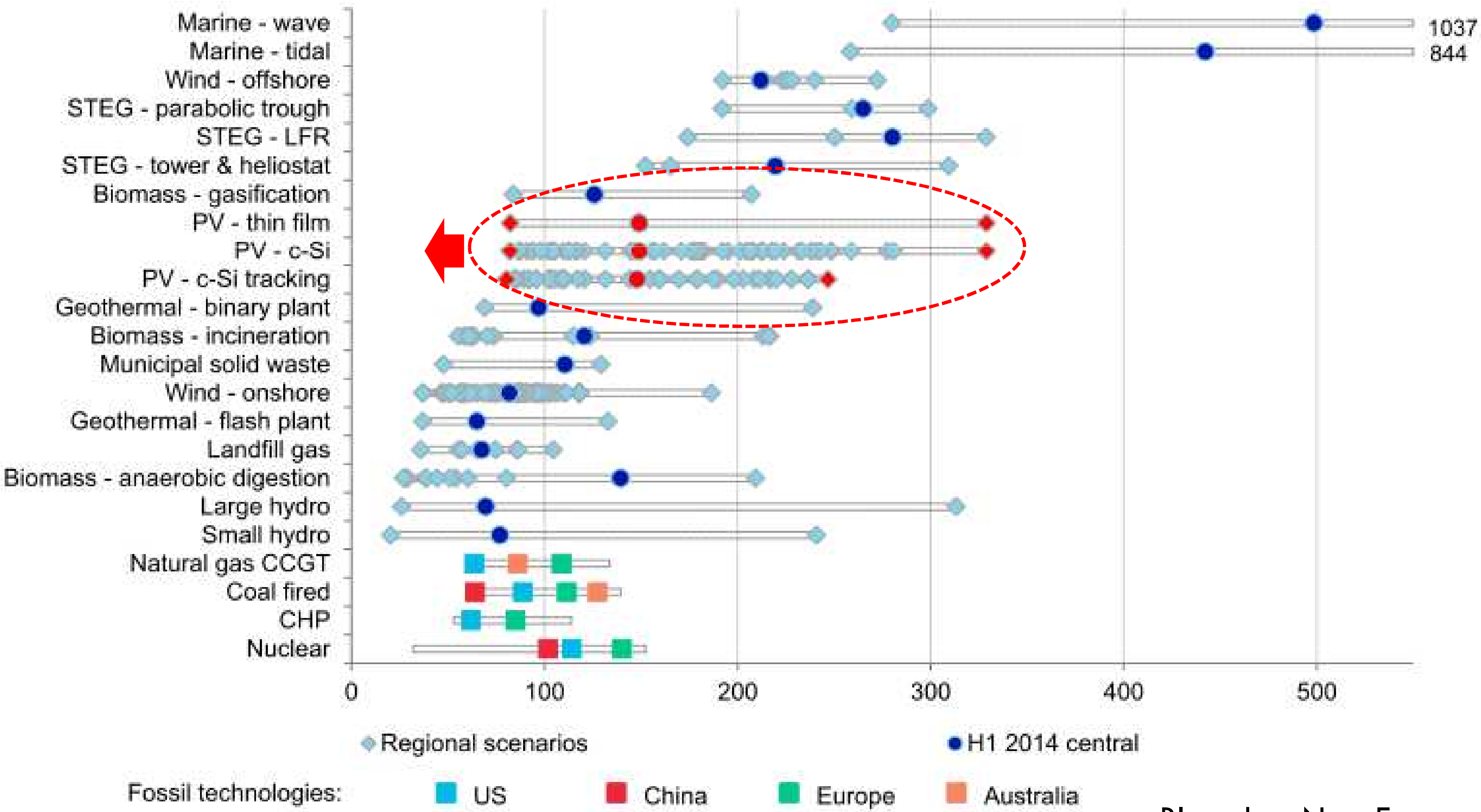
	LCOE ($/KWh)	Cost of Electricity ($/KWh)	Type	Solar Vs Avoided Cost (5kW Panel)
Middle East/Africa/Europe				
Saudi Arabia	$0.14	$0.07	Wholesale	$0.07
South Africa	$0.15	$0.21	Residential	-$0.06
Turkey	$0.19	$0.18	Residential	$0.00
Turkey	$0.19	$0.14	Commercial	$0.04
Israel	$0.14	$0.18	Residential	-$0.04
Germany	$0.26	$0.15	Residential	$0.11
Germany	$0.26	$0.13	Industrial	$0.13
Italy	$0.18	$0.38	Residential	-$0.20
Italy	$0.18	$0.35	Industrial	-$0.18
France	$0.25	$0.17	Residential	$0.07
France	$0.25	$0.15	Industrial	$0.09
Spain	$0.18	$0.19	Residential	$0.00
Spain	$0.18	$0.14	Industrial	$0.05
United Kingdom	$0.23	$0.15	Residential	$0.08
United Kingdom	$0.23	$0.15	Industrial	$0.08
Greece	$0.15	$0.29	Residential	-$0.14
Greece	$0.15	$0.19	Industrial	-$0.04

Source: Deutsche Bank, Saudi Electric Company, Eksom,EuroStat, NASA

Deutsche Bank, 2013

LCOE analysis

Why buy electricity if I can do it cheaper?



Bloomber New Energy Finance, 2013

The PV market is becoming truly global

- Reality exceeds all expectations: cumulative installed and supply chain capacity, cost competitiveness and global development.
- In 2011, Europe accounted for 74% of the world's new PV installations; in 2012 this number was around 55%. In 2013 it is almost certain that the majority of new PV capacity in the world will be installed outside of Europe.
- For the first time since 2003 Europe lost its leadership to Asia in terms of new installations. China was the top market in 2013 with 11.8 GW of which 500 MW represent off-grid systems.
- Strong PV technology price decreases and electricity prices on the rise have helped drive momentum toward "dynamic grid parity".
- Distributed generation, electricity storage, and energy management technologies are advancing rapidly and will eventually give a large number of customers, the chance to unplug from the grid. As this occurs, the role of the traditional utility monopoly will shrink.