Applied Solar Expertise

~100% Global Energy Supply with Renewables amidst this Century – from an Economical, Industrial and Technical Point of View

2nd March, 2018
KIT

Dr. Winfried Hoffmann – ASE

Angewandte SolarExpertise

Applied Solar Expertise

Dr. Winfried Hoffmann - current activities as of March 2018

- Independent consultant to companies and business angel to start-up‘s
- Member of the board of trustees at Institute for Solar Energy Research in Hameln (ISFH, Hameln), Center for Solar Hydrogen (ZSW, Stuttgart) and DLR Institute (Oldenburg)
- Lectures at the universities in Konstanz and Freiburg

CV Winfried Hoffmann

- Study of solid state physics (1974 **diploma superconductivity**) and 1977 PhD in biophysics – Post-Doc and senior lecturer in London
- 1979 NUKEM R&D photovoltaics (Thin-film Cu_2S/CdS, c-Si ,dye solar cells)
- 1988 NUKEM business unit PV und new materials
- 1985 board member **BSW Solar** (Bundesverband SolarWirtschaft) … until 2010
- 1987 member of board of trustees at **FhG – ISE** … until July 2016
- 1994 **CEO at ASE** – Applied Solar Energy GmbH (50%/50% JV DASA/NUKEM)
- 1996 → 100% NUKEM → RWE Solutions AG (ASE → „RWE Solar“)
- 1997 board member EPIA (**European PV Industry Association**)… until 2014
- 2002 **CEO at RWE SCHOTT Solar** GmbH (50% SCHOTT AG/RWE Solutions AG)
- 2005 Member of the Management Committee at SCHOTT Solar GmbH
- 2007 CTO at **Applied Materials** Inc (USA) and MD at German GmbH&Co KG
- 2009 Member of board of trustees at **HZB** (Helmholtz Zentrum Berlin) ... until 2014
- 2010 Member of supervisory board at **SMA Solar Technology AG** … until 2016
- 2011 Own independant consulting company ASE – Applied SolarExpertise
- 2012 Chairman of the supervisory board at **Solar Fabrik AG** … until 2016

Content

(1) Global Energy Needs - Today & Tomorrow

(2) Renewable Energies

(3) PV Market and Application

(4) PV Physics

(5) PV industrial needs

(6) Price Experience Curves

(7) PV systems & Grid Integration

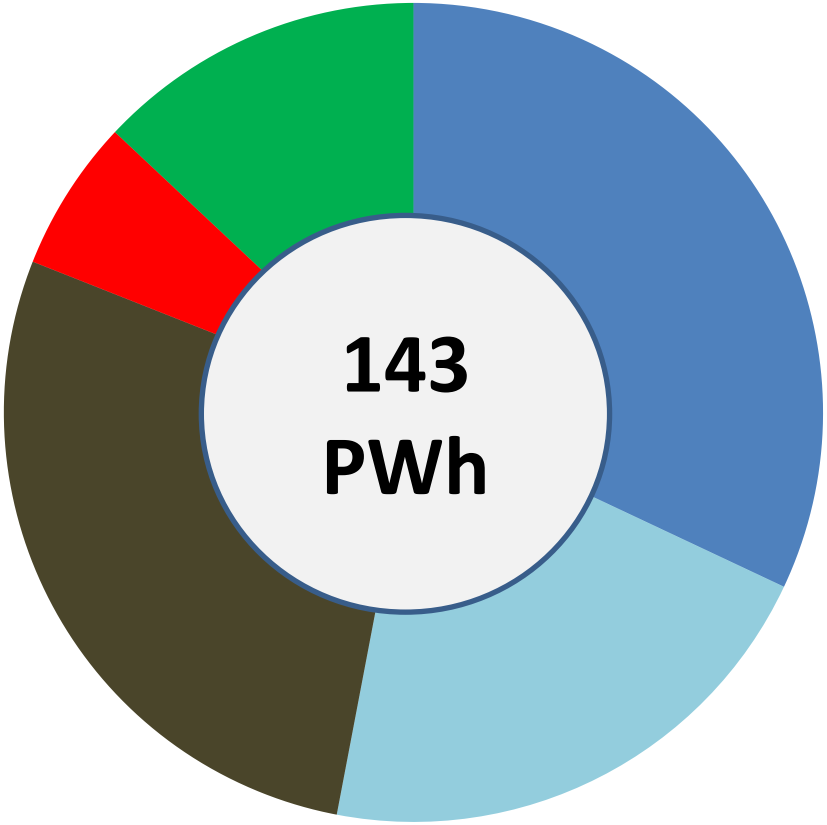
(8) Future Scenarios

Faktencheck
- Energiesituation ~2010 -

Maßnahmen zur Steigerung der Energieeffizienz

Source:

Primary energy split (~2010)



🟦 oil [~1/4 +]

🟦 gas [~1/4 -]

🟫 coal [~1/4 +]

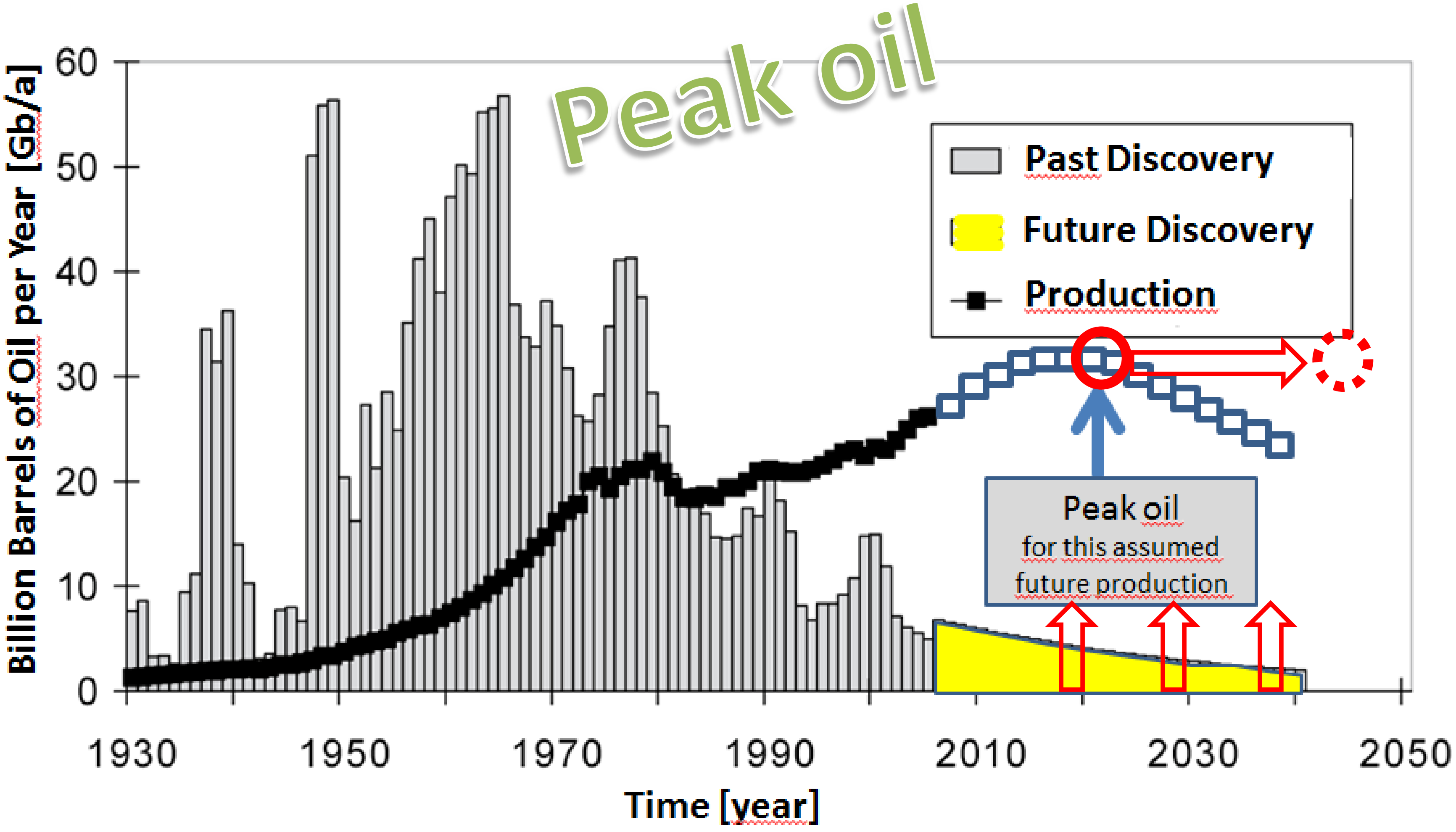
🟥 nuclear [~1/3]

🟩 renewables [~2/3]

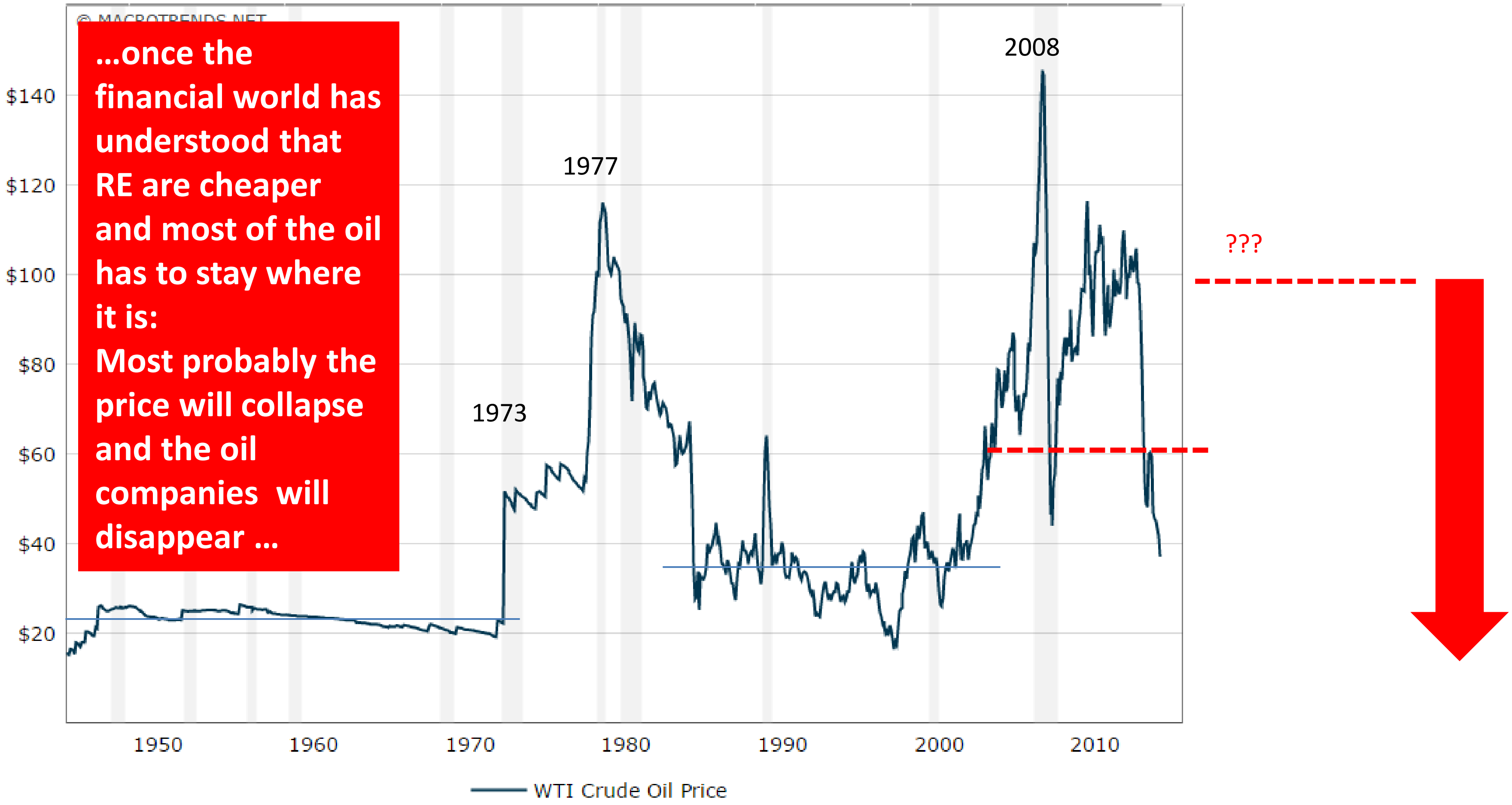
nuclear + renewables: [~1/4 -]

Source: IEA

Past and future oil discovery versus production and consumption



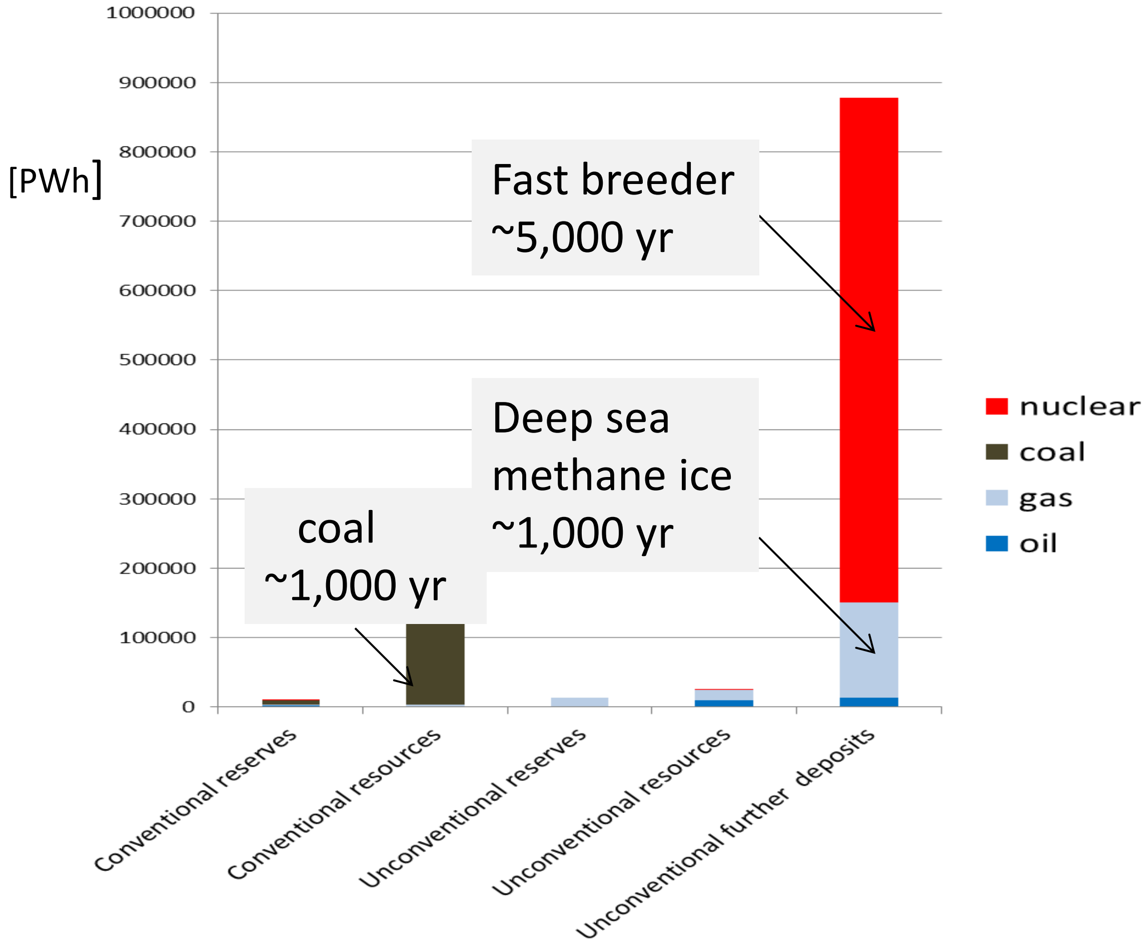
Crude Oil Price Development



…once the financial world has understood that RE are cheaper and most of the oil has to stay where it is: Most probably the price will collapse and the oil companies will disappear …

Source: Macrotrends (2015)

Reserves, Resources and further Deposits for exhaustible Energy Sources



Fast breeder
~5,000 yr

Deep sea
methane ice
~1,000 yr

coal
~1,000 yr

- Current Primary energy usage ~140 PWh/year
- → >7,000 years!

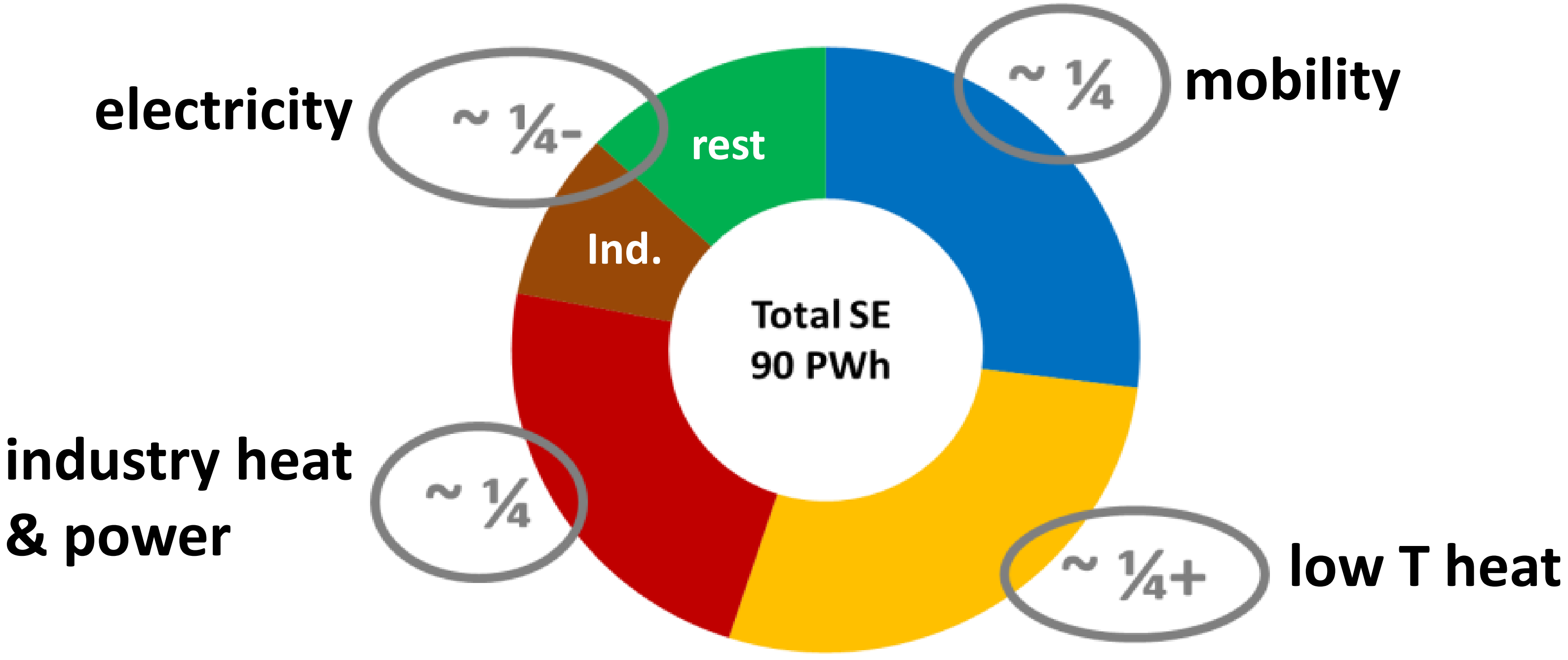
Source: WBGU (2011)

The „1.5° or even 2°C goal“ is at risc

- ✓ If we *quickly and dramatically decreased* the annual CO2 amount to the atmosphere by replacing fossil fuels by Renewables and could *keep all other parameters constant*, we could have a chance to keep the T-increase at *~2°C*
- ✓ Given the *current trend* of CO2 emissions due to burning of fossil fuel (+cement and cow&sheep) it is much more probable that this T-increase is driven ***towards ~4°C***
- ✓ By adding the *other GhG* (mainly methane) there is unfortunately a further T-increase to be expected **(?5, 6, 7? °C** in total)
- ✓ Such a quick and high T-increase has been observed last time *~50 millions of years ago* (resulting in the extinction of the dinoaurs)
- ✓ What we already observe today with increasing intensity in the future is
  # not more but heavier tornados, taiphoons and hurricanes
  # melting of glaciers globally (→ droughts in summer and floods in spring/autumn)
  # sea level rise (~m by 2100 and dramatically more thereafter
  # severe changes in local climate due to changes of ocean streams (e.g. gulf)
  # acidification of sea water resulting in extinction of coral reefs
  # extinction of many more animal and plant species

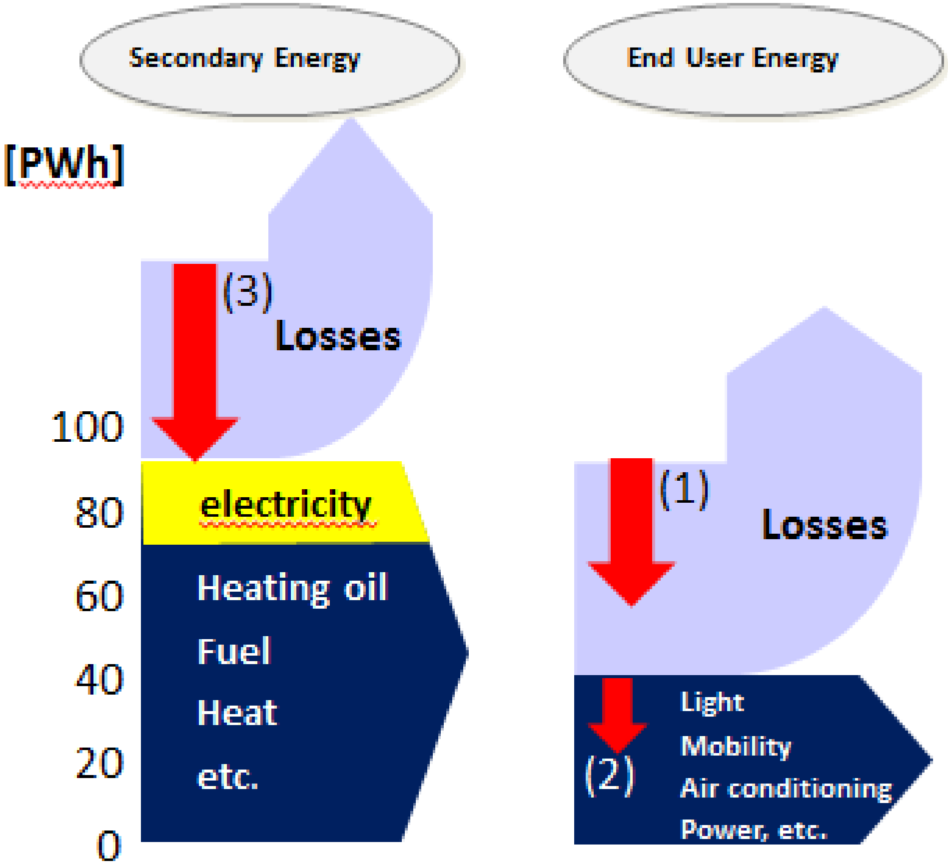
Source: Rahmstorf & Schellnhuber(2012), Own considerations

Secondary Energy (SE) split into the Energy Sectors (2010)



Source:

Energy Efficiency Measures



ref.: World Energy Council, Greenpeace, IEA,
own estimates

Importance of Energy Efficiency

Example Car

Fuel → Otto engine → car from A to B

(1) E-Motor/Hybrid
(2) *In Future:* E-Motor only 50% SE saving – same for PE if RE!!

Example Lighting

Electricity → bulb → light (Lumen)

(1) Effic. Lamp
(2) (O)LED 50+% SE saving

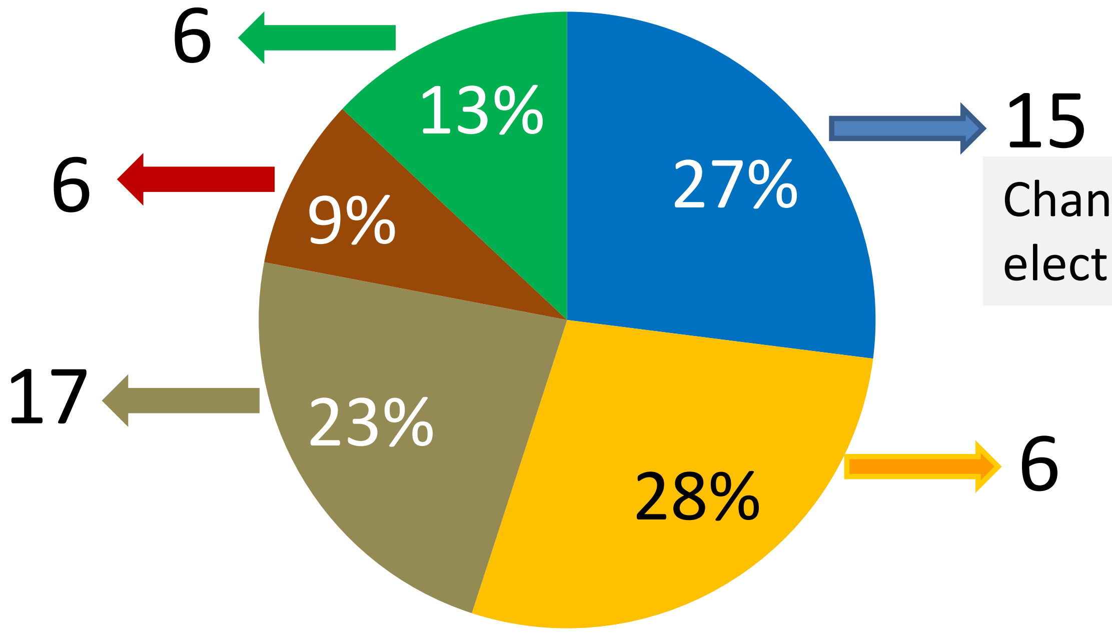
Example Zero Emission House - insolation

Efficient insolation / heat pump / solar thermal to stop burning fossil resources for heating/cooling 50+% SE saving

Impact of „mild“ efficiency measures on today‘s secondary energy

🟦 mobility 🟨 low temp heat 🟫 industry

🟫 electricity industry 🟩 electricity rest **Total 90 PWh ➡ 45 PWh**



Change from oil to electricity/power fuel

Source: Own considerations

Increase of efficiency to decrease SE while preserving same quality of life

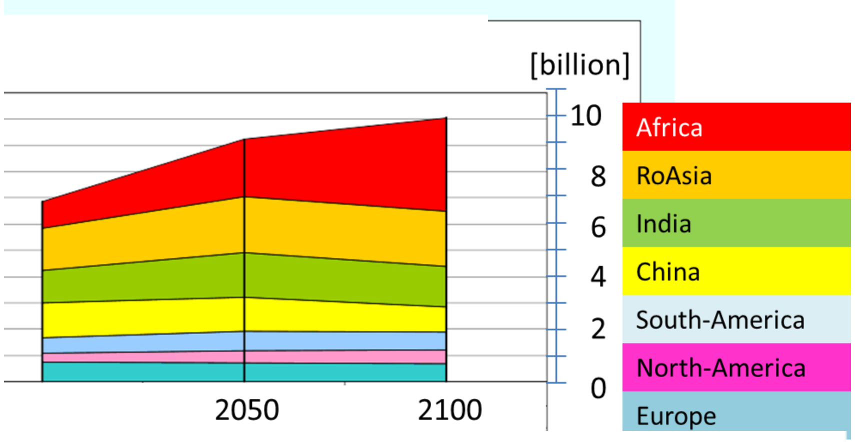
- The „mild“ efficiency measures described before result in an efficiency increase by a factor of 2 (SE from 90 to 45 PWh)

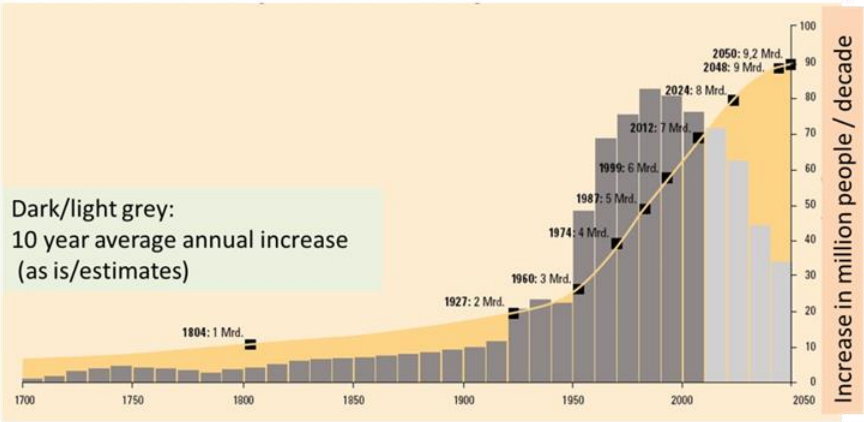
- Von Weizsäcker et al have elaborated on examples to double this factor towards 4
  The same authors have concluded that a factor 5 could be feasable (→ today‘s SE would only be 18 PWh!):
  „massive“ measures

- „mild“ is too easy and „massive“ too ambitious
  → „realistic“ may be a factor of 3 (SE 30 PWh)

Source: Own considerations, von Weizsäcker etal.

Development of global population




Dark/light grey:
10 year average annual increase
(as is/estimates)

Source: UN

Future Secondary energy needs
(= PE if 100% RE are used)
and solving inequity

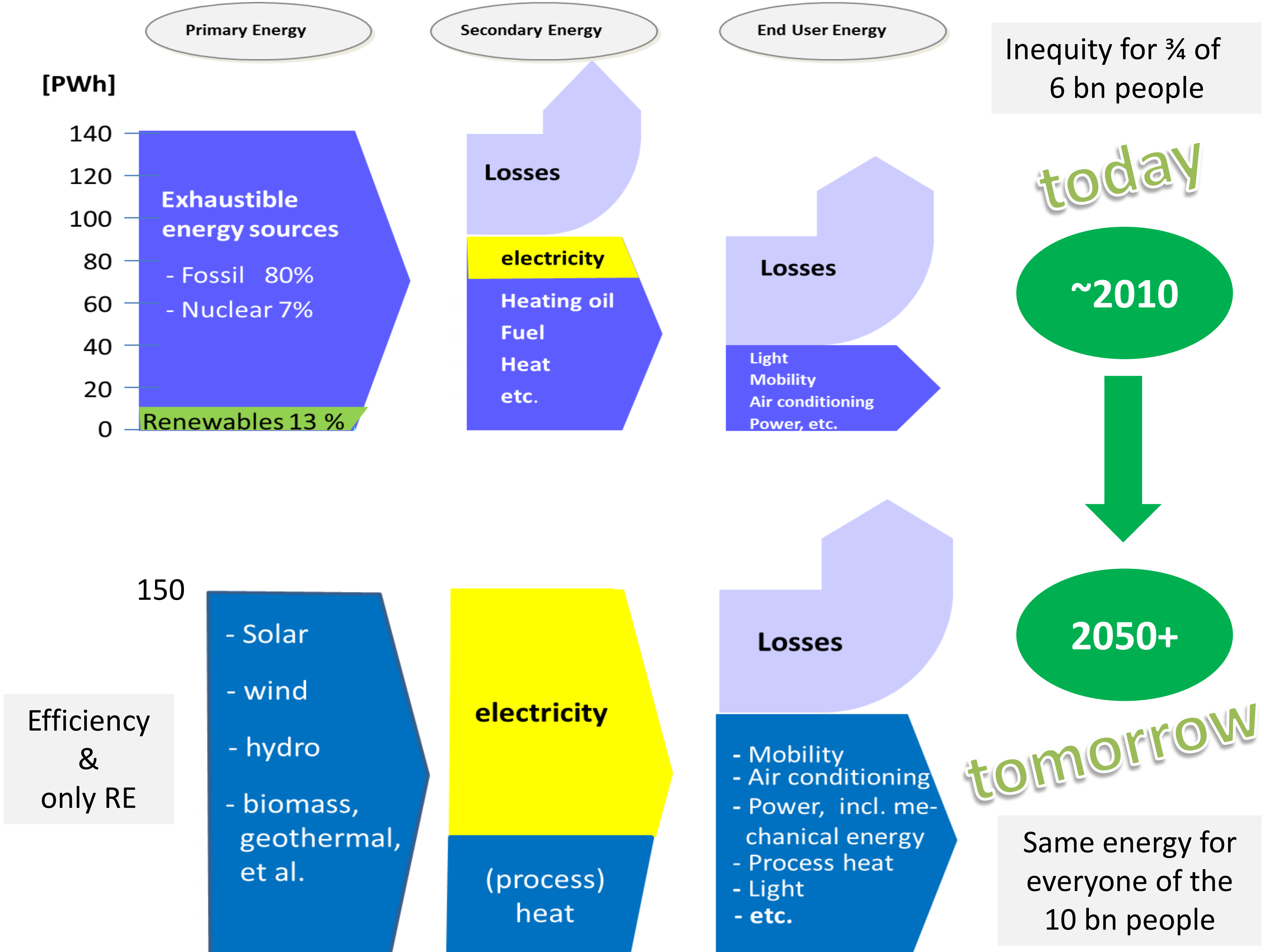
rep.: with today‘s „unfair“ energy distribution, (1/4=1,5 bn) use ¾ of PE, hence 140 PWh x ¾ x 2/3 = 70 PWh for one bn@ HQ → 700 PWh für 10 bn; The corresponding SE is 90 PWh x ¾ x 2/3 = 45 PWh für 1 bn, 450 PWh für 10 bn@HQ

With „mild“ efficiency increase **(Factor 2):**
SE only half of 45 PWh or 22,5 PWh for 1 bn@HQ →
225 PWh for **10 bn** with fair energy distribution and HQ (**high quality) for ALL**!

Using „moderate“ efficiency increase **(Factor 3):**
SE only one third of 45 PWh or 15 PWh für 1 bn@HQ →
150 PWh for 10 bn with fair energy distribution and HQ (high quality) for ALL!

With „massive “ efficiency increase (**Factor 5**, von Weizsäcker et al.):
SE only one fifth of 45 PWh or 9 PWh for 1 bn@HQ →
90 PWh for 10 bn with fair energy distribution and HQ (high quality) for ALL!

Source: Own estimates (Factor 2 und 3), von Weizsäcker et al (Factor 5)



Primary Energy

Secondary Energy

End User Energy

Inequity for ¾ of
6 bn people

today

~2010

Exhaustible energy sources

- Fossil 80%
- Nuclear 7%

Renewables 13 %

Losses

electricity

Heating oil
Fuel
Heat
etc.

Losses

Light
Mobility
Air conditioning
Power, etc.

2050+

- Solar
- wind
- hydro
- biomass, geothermal, et al.

electricity

(process)
heat

Losses

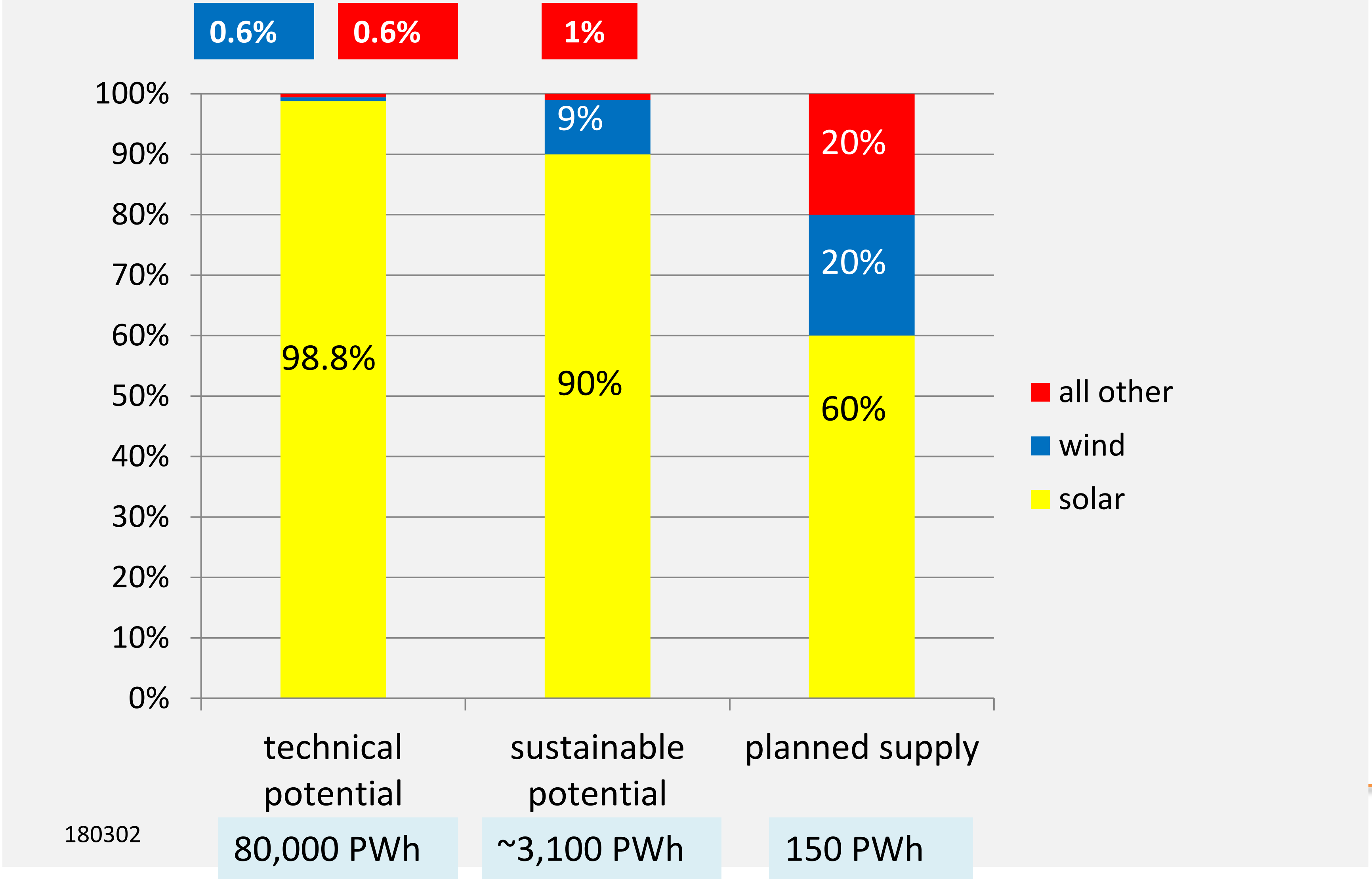
- Mobility
- Air conditioning
- Power, incl. mechanical energy
- Process heat
- Light
- **etc.**

Efficiency
&
only RE

tomorrow

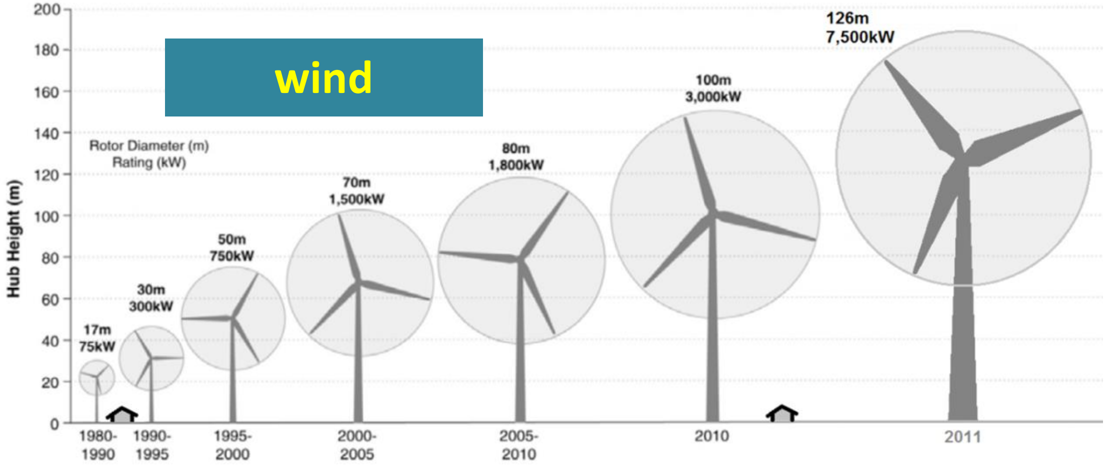
Same energy for
everyone of the
10 bn people

Technical and sustainable potential for the various RE (WBGU 2008)



Portfolio of Renewable Energies

wind



biomass

Solar thermal – hot water & CSP

Parabolic troughs

Dish

Power tower

hydro

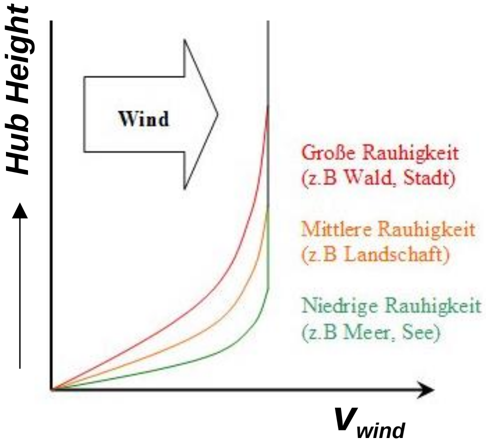
geothermal

PV solar electricity

Wind Energy

Drive for high hub heights & larger Rotor Blade Diameters

$$P_{wind} \sim d_{blade}^{2} \times v_{wind}^{3}$$



- On-shore 2,000 - 3,000 full-load hours
- Off-shore 3,000 - 4,000 full-load hours

Impact due to higher windmills and larger rotors

Hub height [m]	85m	140m
Blade length [m]	~40	~70
Resulting power increase	:= 1	→ x 1.75^^2 = 3

Source: Winfried Hoffmann (2016)

Impact due to higher windmills and larger rotors

Hub height [m]	85m	140m
Blade length [m]	~40	~70
Resulting power increase	:= 1	→ x 1.75^^2 = 3
Average wind velocity [m/s] (Hohe Wurzel, Germany)	6.03	6.3
Resulting power increase	:= 1	→ x 1.045^^3 = 1.14

Source: Winfried Hoffmann (2016)

Growian, die "*Gro*ße *Wi*nd *An*lage"

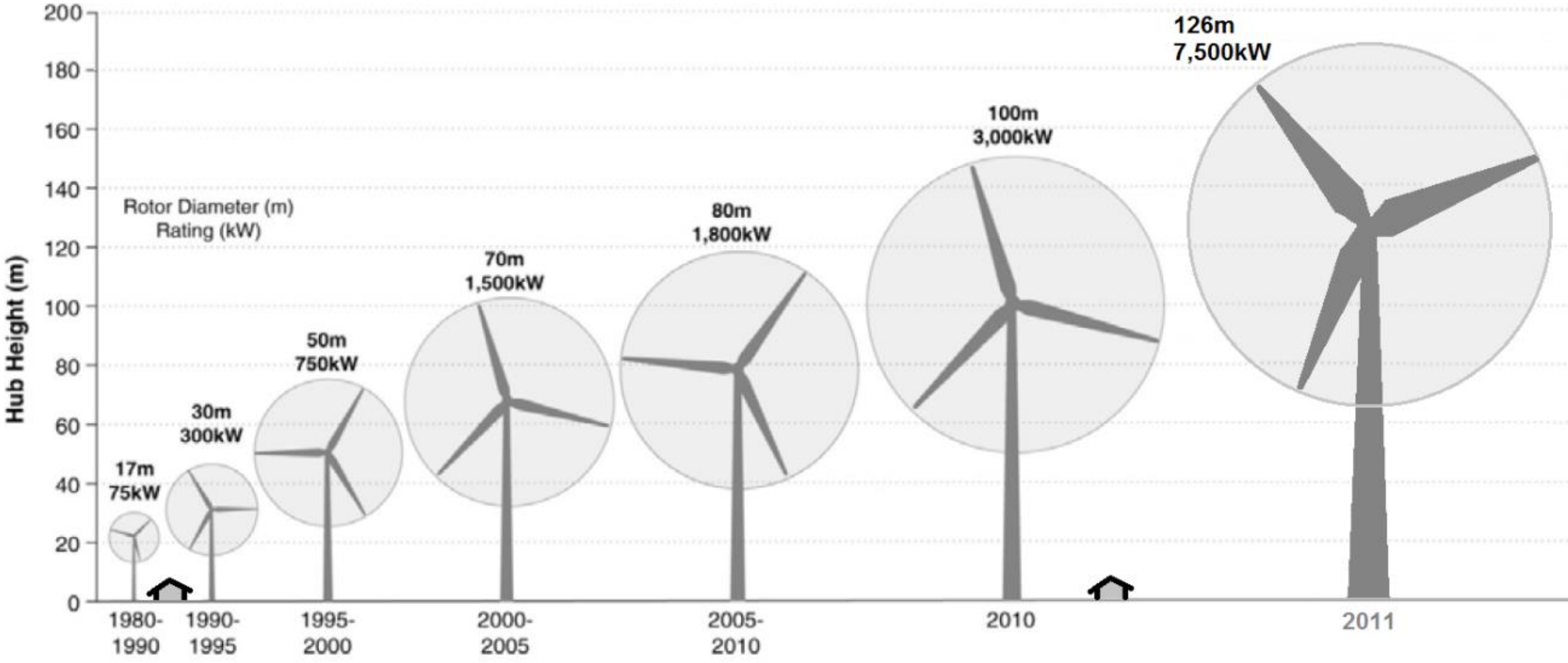
Effective Power	**3** MW
Technology Basis	**30 kW**
Installation Date	**1980**
Demounting Date	1987

Up-scaling factor x100

Experience shows << x10

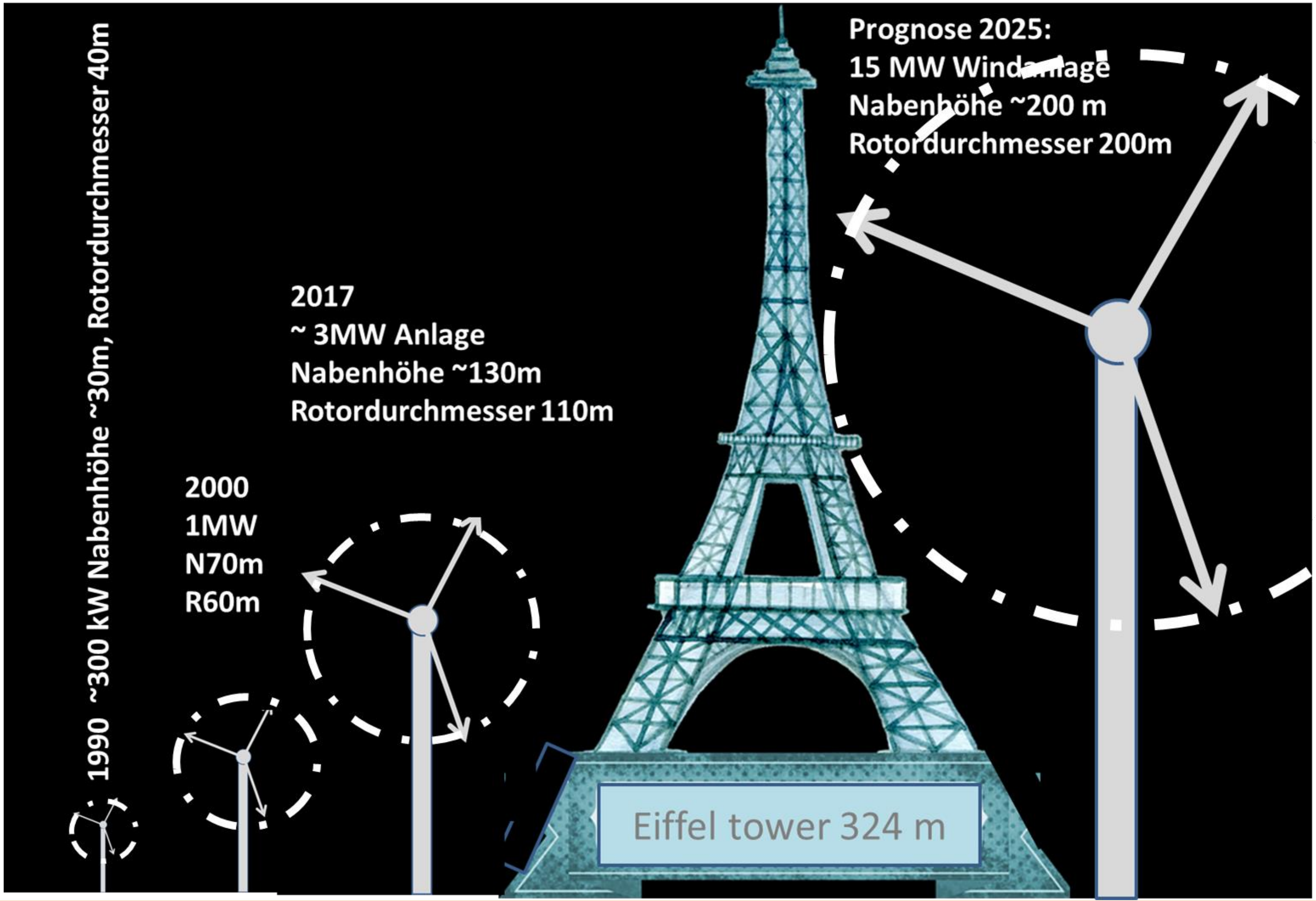
In-Efficient Technology "Push"

Wind energy development
…due to market support (FiT)



Source: WindEurope

… further development …

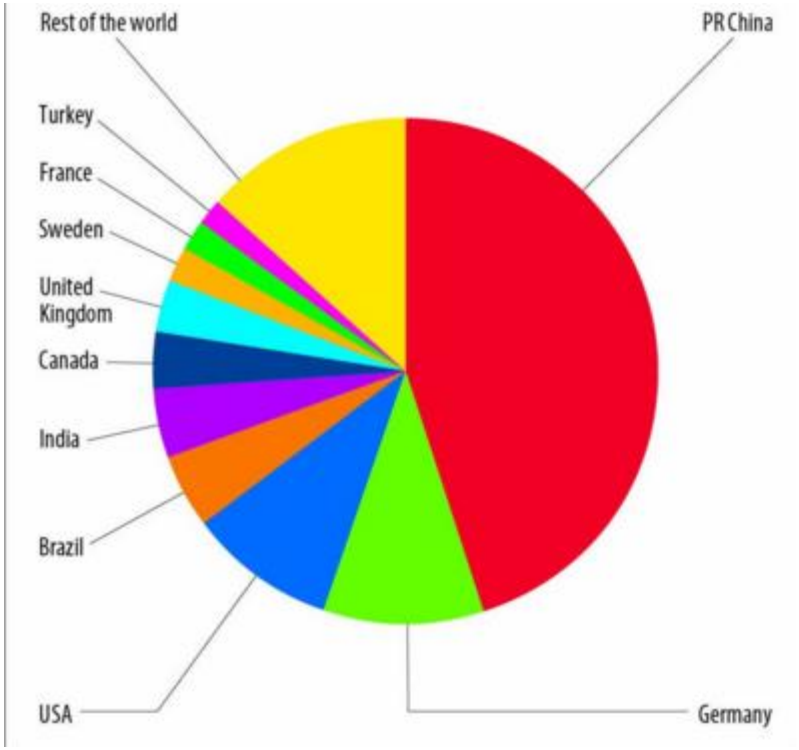


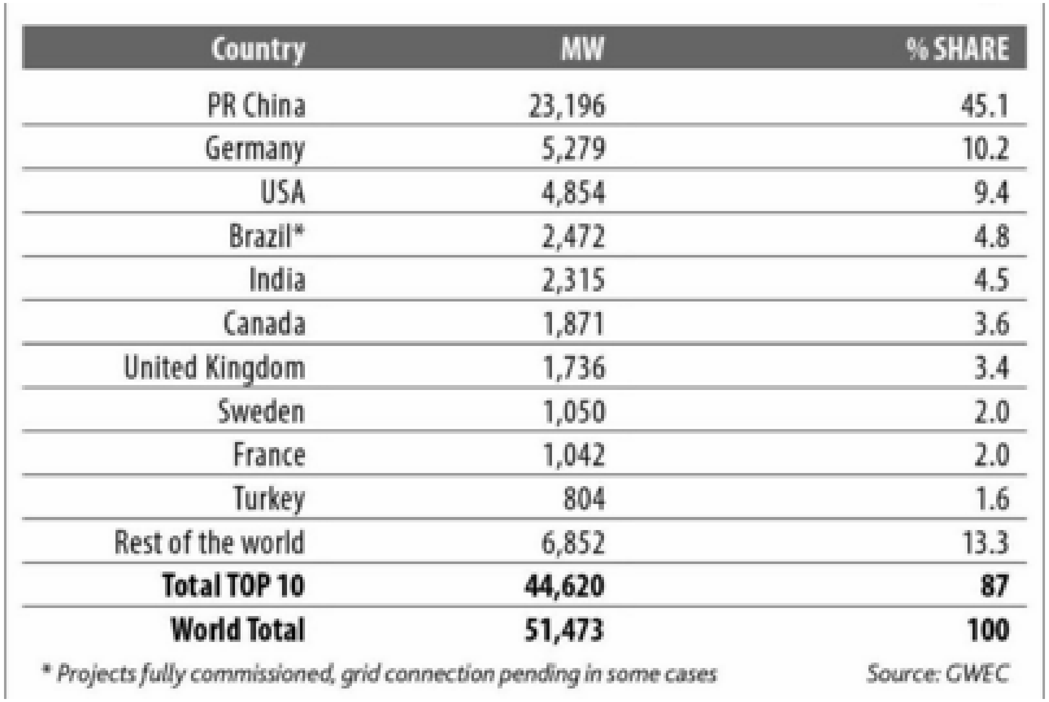
5 MW Wind Converter

Parallel development of adequate Infrastructure!

Source: REpower Systems AG

TOP 10 countries with wind installations (2014)





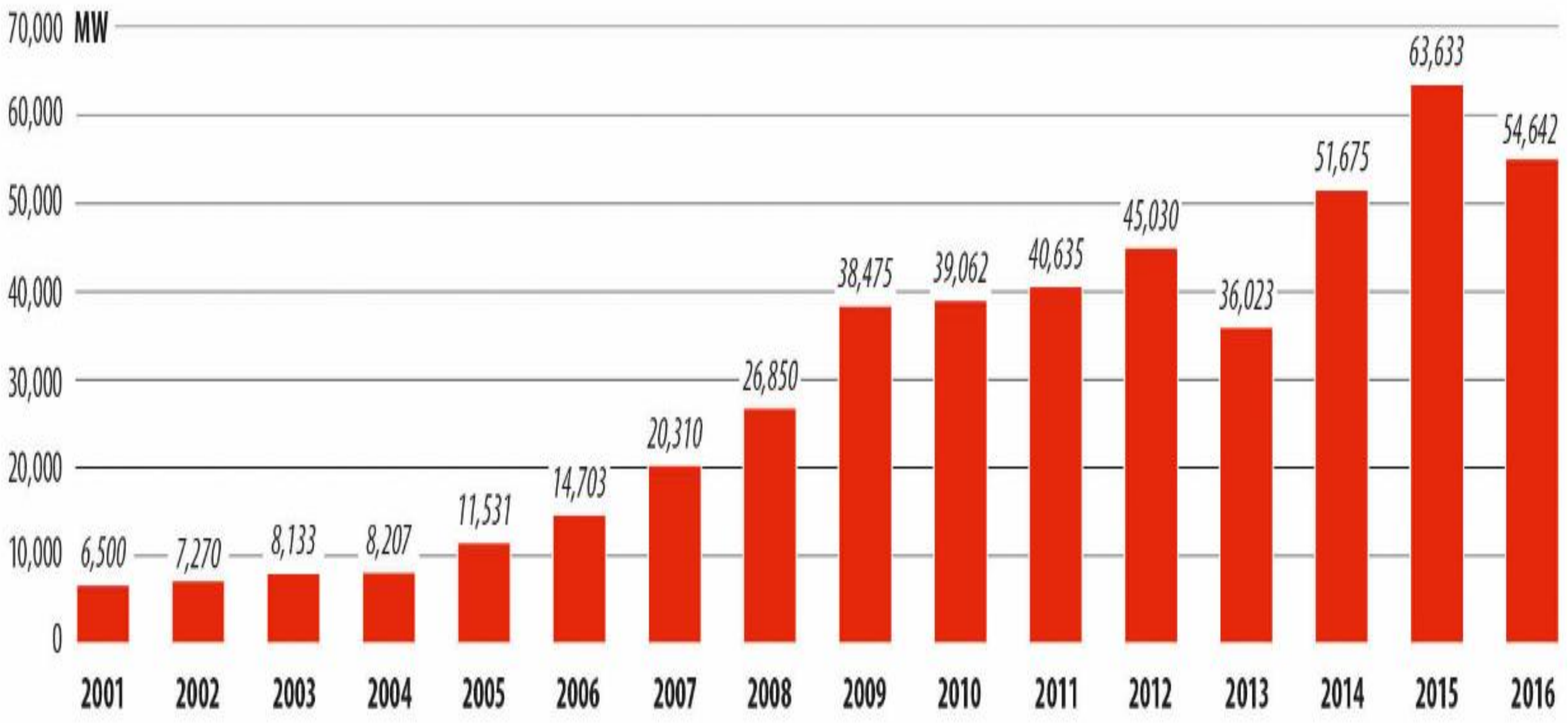
Country	MW	% SHARE
PR China	23,196	45.1
Germany	5,279	10.2
USA	4,854	9.4
Brazil*	2,472	4.8
India	2,315	4.5
Canada	1,871	3.6
United Kingdom	1,736	3.4
Sweden	1,050	2.0
France	1,042	2.0
Turkey	804	1.6
Rest of the world	6,852	13.3
Total TOP 10	**44,620**	**87**
World Total	**51,473**	**100**

** Projects fully commissioned, grid connection pending in some cases*

Source: GWEC

Source: GWEC (2015)

Global annual installed wind capacity



Source: GWEC (2015)

Average annual growth from **1997 to 2014** was **23%,** from **2001 to** ~60 GW in **2016** was **16%**

Solar Thermal Energy

Residential low temperature thermal energy

Heat for hot water, house heating and climatisation

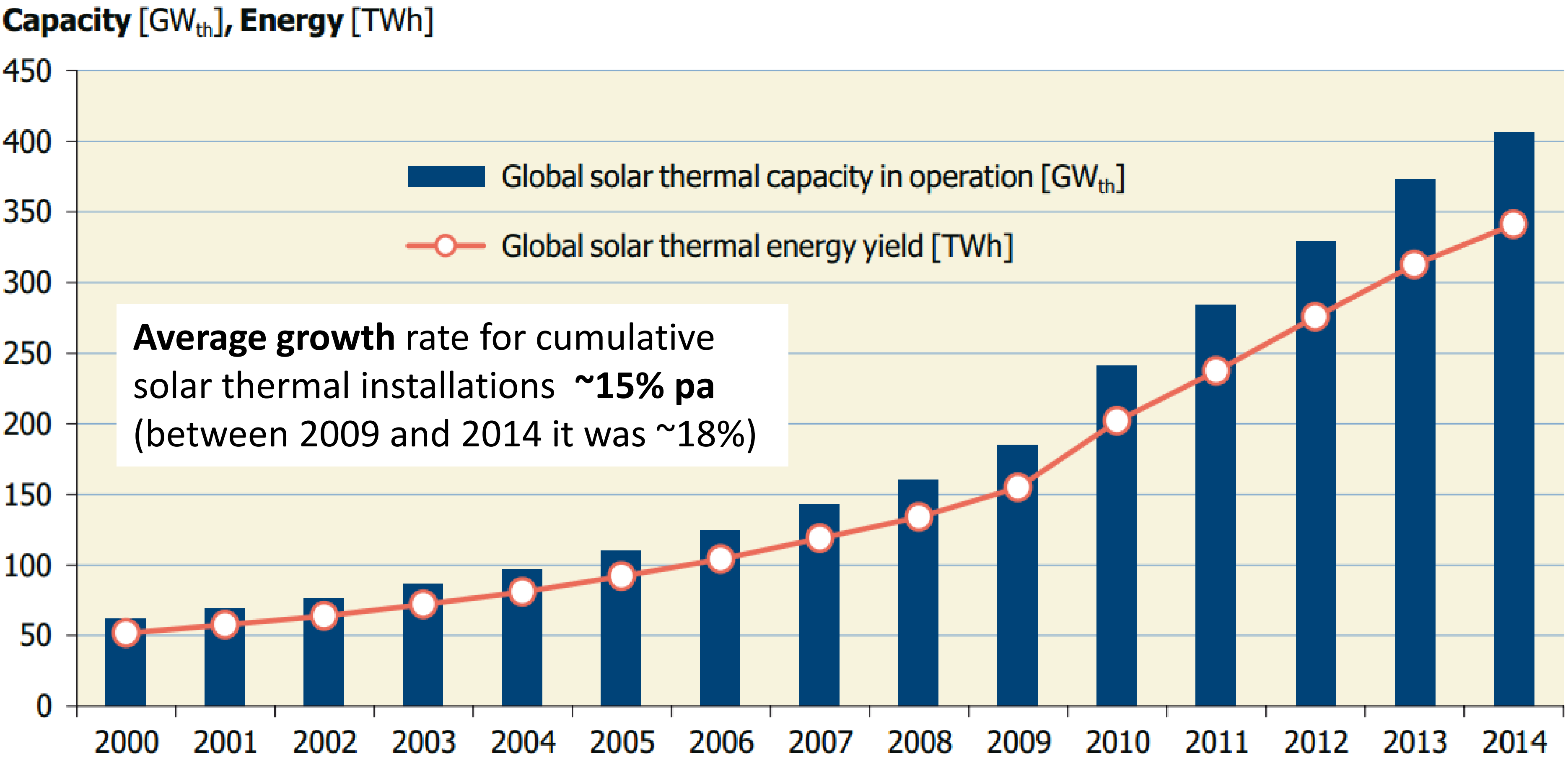
High temperature solar thermal power plants

Generation of electricity at the sunbelt of the earth

TOP 10 countries with solar thermal installations (2010)

Country [1m² =~ 700 W_{th}] [1 W_{th} =~ 700 Wh/a]	Cumulative solar thermal installations end 2010 [million m²]	[GW_{th}]	Annual solar thermal installations in 2010 [million m²]	[GW_{th}]
China	194	135.8	49.0	34
EU 27	21.6	15.1	3.1	2.2
Turkey	20.6	14.4	1.7	1.2
Japan	6.2	4.3	<0.1	<0.1
Brazil	4.4	3.1	0.5	0.4
Israel	4.0	2.8	0.3	0.2
India	3.1	2.2	0.6	0.4
US	2.7	1.9	0.2	0.1
Australia	2.5	1.7	0.4	0.3
Taiwan	1.9	1.3	<0.1	<0.1
RoW	~10	~7	~2	~1.4
Total	~271	~190 (~133TWh)	57.9	~40 (~28TWh)

Global solar thermal capacity and annual energy yields



Average growth rate for cumulative solar thermal installations **~15% pa** (between 2009 and 2014 it was ~18%)

Source: IEA-SHC (2015)

Solar Thermal Power Plants

- Concentrated Solar Power (CSP) requires direct radiation
- Often in combination with thermal storage
- Electrification via heat engine: steam engines, Sterling motor

Parabolic troughs

Dish

Power tower

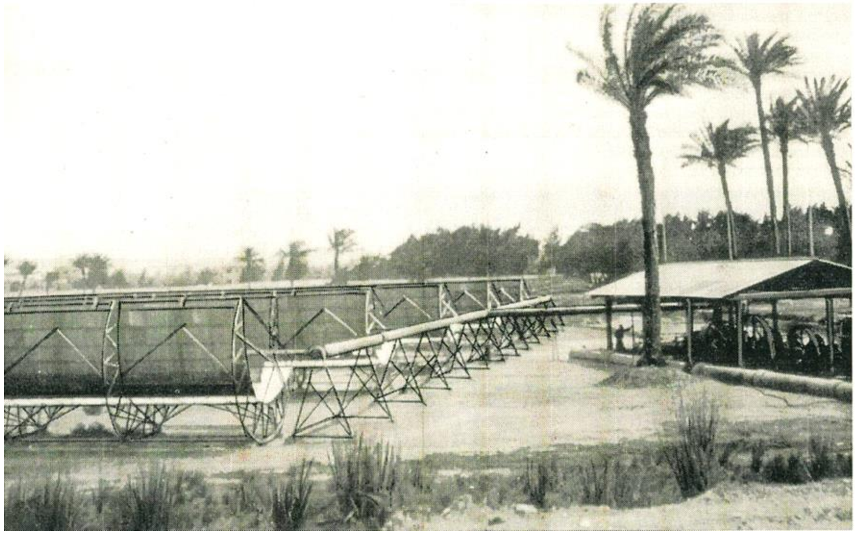
- Thermal efficiency: up to 70%
- Electrical efficiency: up to 16%
  (Dish design combined with Stirling motor)

Full Load Hour per Year	Full Load Availability
1800 - 4500	20% - 50% *)

*) 50% only if heat storage is included in CSP

First Parabolic Trough Power Plant

Egypt in 1914



Collector Field and Power Block designed by Shuman in Meadi near Cairo (1914)
5 rows with 62 m, steam turbine 120 HP

(technisches Archiv des Deutschen Museums)

Hydropower: China‘s Three gorge dam with power station

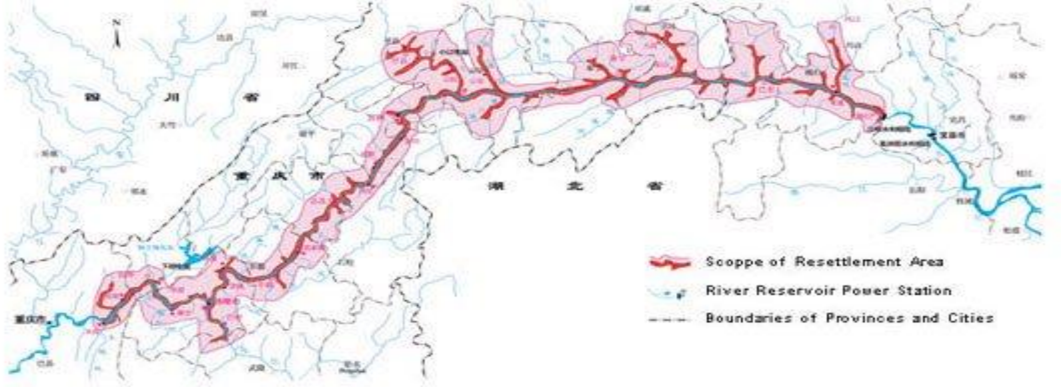


Diagram of the TGP inundation area

China Three Gorges Project ©2002 All rights reserved

dam 185 m high, 200 m long
Volume 40 bn m³
Length storage lake 620 km
23 GW power, ca. 90 TWh/a
25 … 50 bn $ Invest

Hydro Energy (TOP 10 countries and projects)

Country	Annual electricity production [TWh]	% of country’s e-consumption	10 biggest hydro power stations	Located in country	Installed power [GW]
China	694	22	Three Gorges Dam	China	23
Brazil	430	86	Itaipu	Brazil/Paraguay	14
Canada	377	61	Guri	Venezuela	10
United States	328	6	Tucurui	Brazil	8
Russia	165	18	Grand Coulee	US	7
India	132	16	Sayano Shushenskaya	Russia	6
Norway	122	98	Krasnoyarskaya	Russia	6
Japan	85	7	Robert- Bourassa	Canada	6
Venezuela	84	69	Churchill Falls	Canada	5
Sweden	67	44	Longtan Dam	China	5
Other	1,014	-	Other		760
Total	3,498	~17 (global)	Total		~850

Past and future growth of hydropower

- **Past growth of hydropower was ~linear from 0.9 PWh in 1965 towards 3.5 PWh in 2011 (~0.5 PWh every 10 years)**

- **The economical, technical and theoretical potential for hydropower was estimated to be ~8, 14 and 39 PWh, respectively**

- **Same growth as past decades (optimistic) it would take ~100 years to reach the economic potential**

Bioenergy

Categories for bioenergy (~2005)

Category	% of total bioenergy	Energy [TWh]
Traditional (firewood for cooking & heating)	86.0	11,954
Modern bioheat	7.5	1,043
Biopower (corresponding to 45 GW)	4.3	598
biofuel		
# bioethanol	1.8	250
# biodiesel	0.4	56
Total	100.0	13,900

Electricity production for PV is 40-80 times more efficient per area compared to biomass

- According to a recent study (Weichgrebe, University of Hannover) the production of corn with subsequent conversion into biogas gives in Germany the equivalent of 16 MWh/ha (=10e4 m^2) and year. Even in the best climate zones and using the quickest growing plants this may be maximally tripled (< 50 MWh/ha)! With 40% efficient power station: 20 MWh/ha electricity.

- The **same area in Germany** with a green field PV plant gives about 800 MWh/ha – ~**40 times of electricity**!
  … and in **southern regions** this can be even **= x 80**!

- Moreover, one could even grow vegetables below the modules (if they are just mounted a bit higher from the ground) or, what is widely used, to have sheeps eating the grass below the modules → **Agro-PV**

- The same qualitative argument works also with wind energy!

Efficiency significantly higher for e-cars with PV electricity compared to biodiesel

Rep.:The max energy yield for biodiesel is 50MWh/ha or **50 kWh/(10m²)**;
With a **diesel engine using 5l/100 km** a car can drive ~**110 km** (5l =~ 45 kWh)

With **10 m² PV** on a house roof in **Germany** between 1.000 and **2.000 kWh** can be produced (module efficiency 10 – 20%);
With a 4 person e-car, using ~**12**-18 **kWh/100 km**, one can drive 5.500 – **16.700 km** – 50 to **150 times** as much as the biodiesel

In **southern regions** with twice solar annual energy yield the range increases to 11.000 … 33.000 km – 100 bis **300 times** the distance compared to the biodiesel grown on the same area of 10 m²

For most applications an annual driving distance of 15.000 to 20.000 km is sufficient!

Source: Own calculations, Weichgrebe (Uni Hannover)

PV Market and Application Evolution

1960s
- Powering satellites

1970s
- Consumer products

1980s
- Remote applications
- First power plant projects (Carissa Plains, 6 MW, US

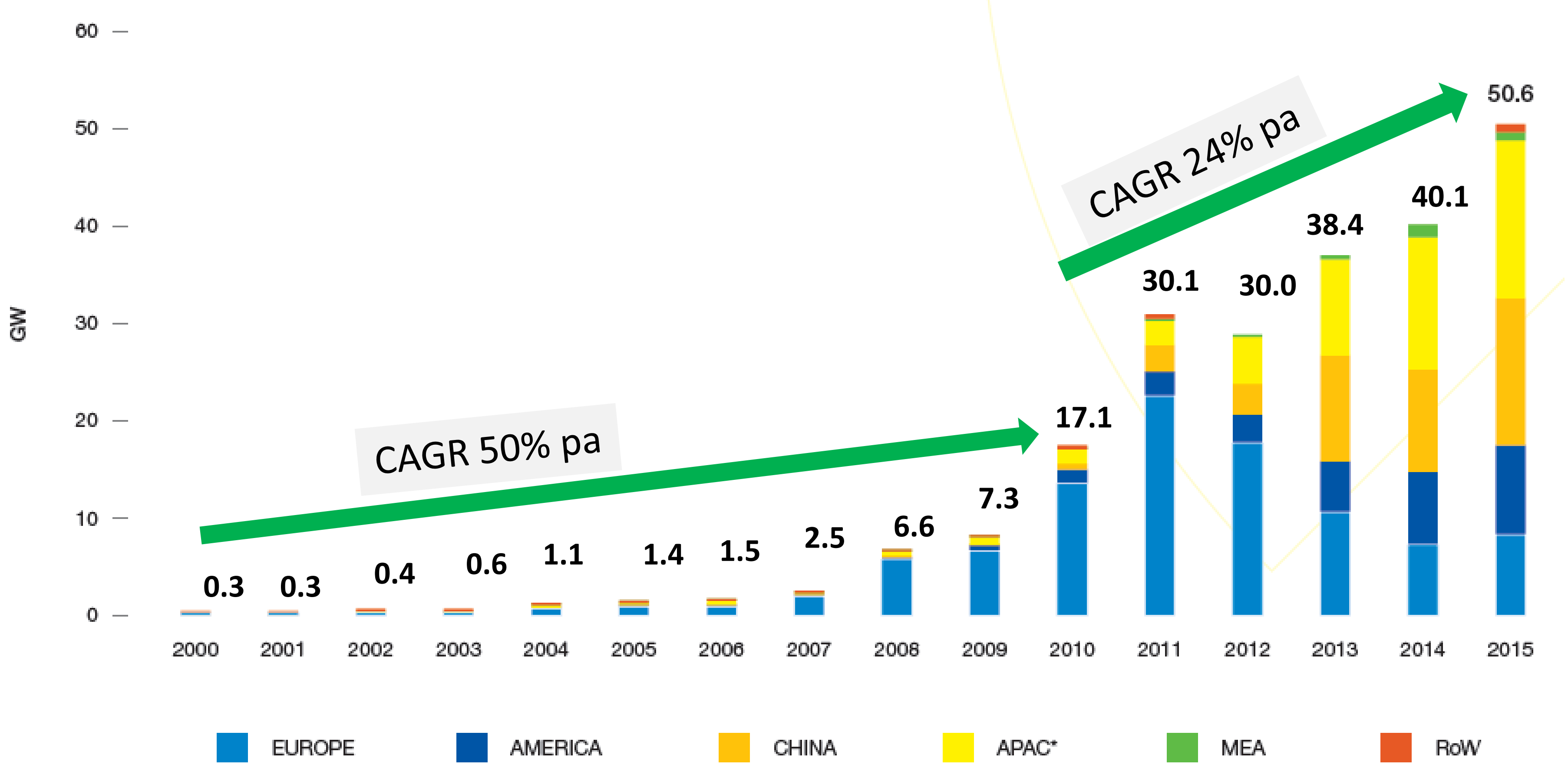
1990s
- First support programs grid integrated
- Ger 1,000 roof, Japan 70,000 roof, Ger 100,000 roof

2000s
- Big boost by Ger FiT, copied in >50 countries
- Boom & bust due to overdoing (Spain 08/09, Cz 10/11

2010s
- Consolidation of the sector globally
- PV competing in the energy sector – huge potential

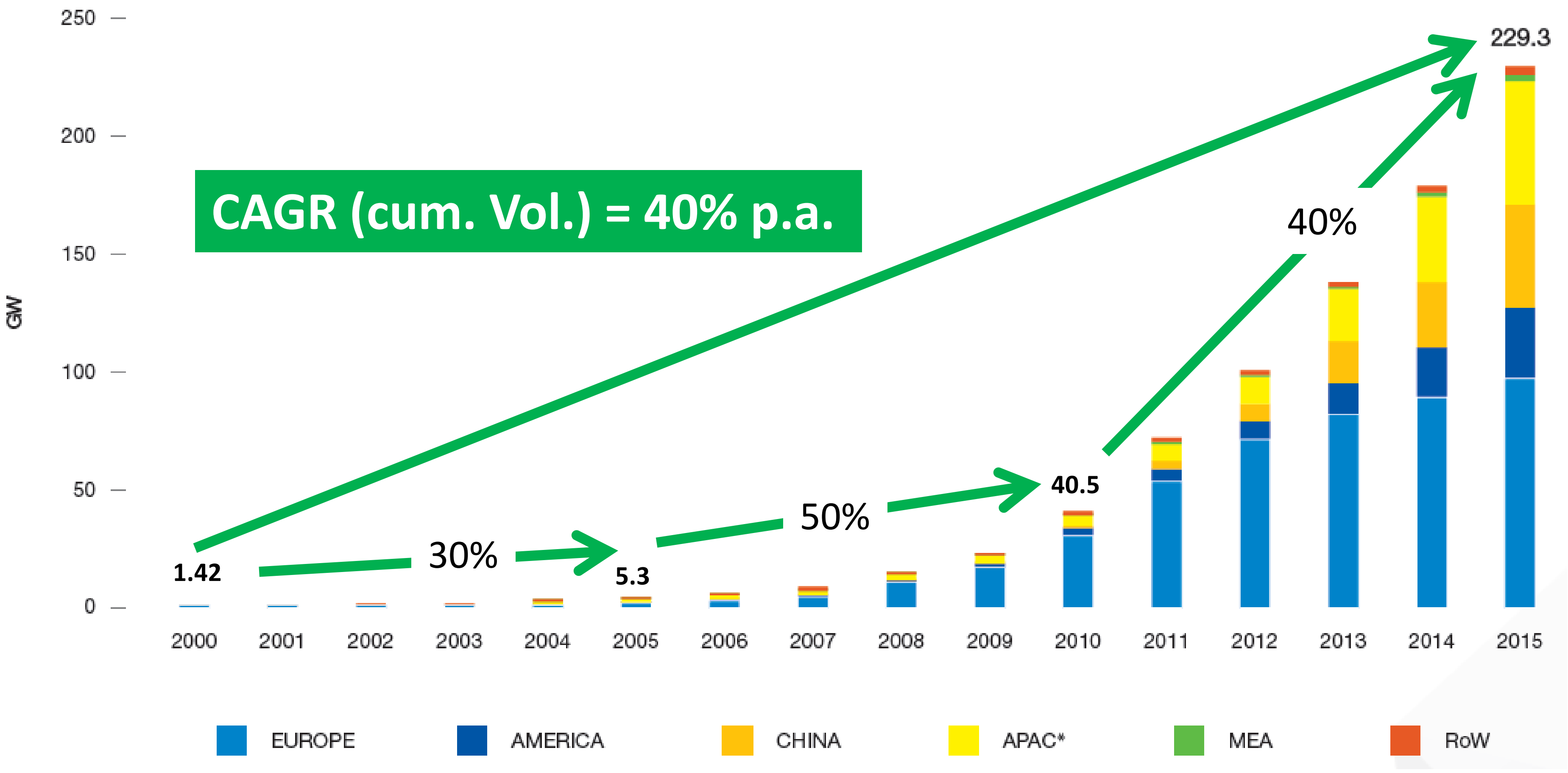
Source: Own data (2013)

Global annual PV installations



Source: SolarPower Europe, GMO 2016-2020

SPE's historic market analysis in cumulative numbers

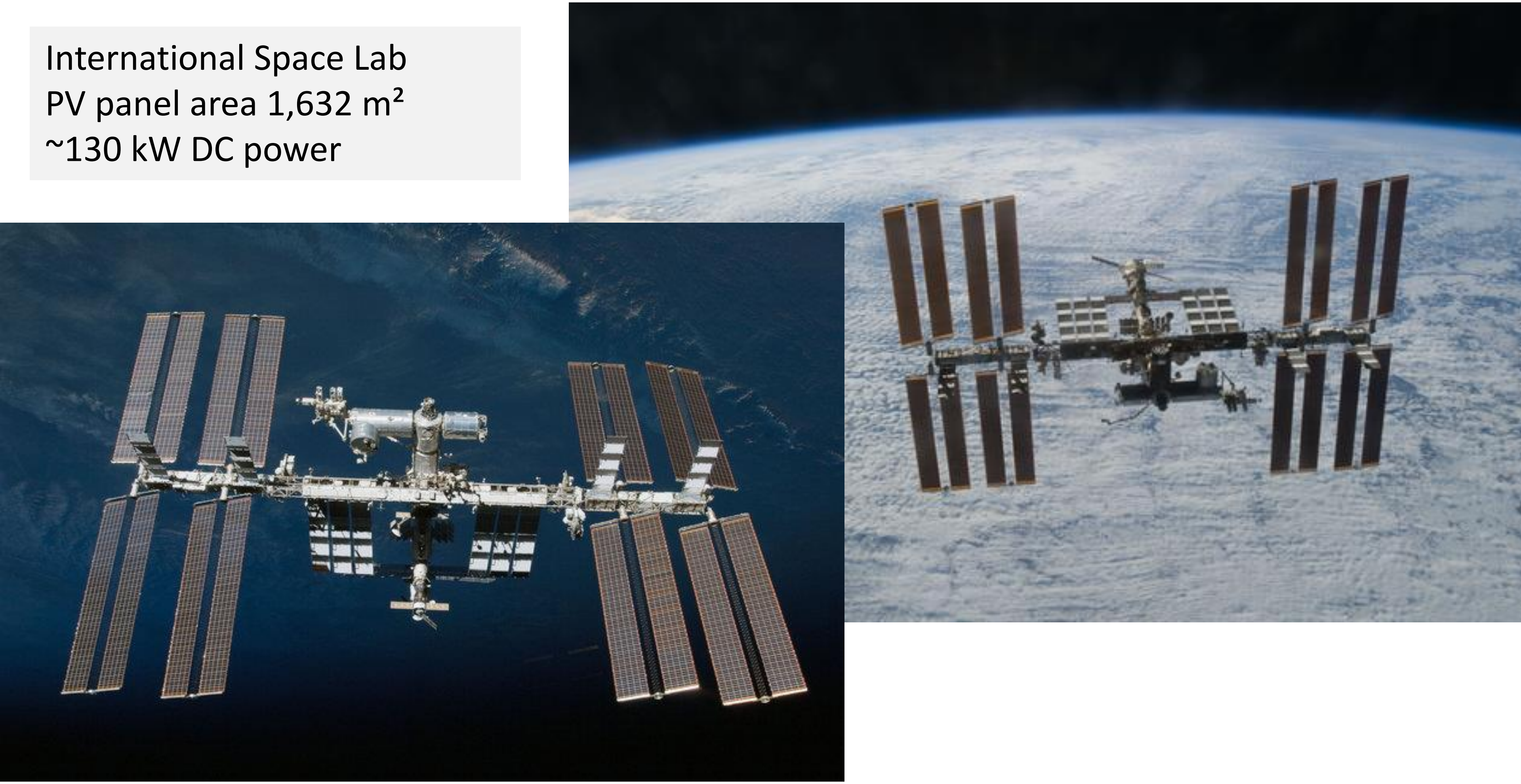


CAGR (cum. Vol.) = 40% p.a.

Source: SPE (EPIA) GMO 2016

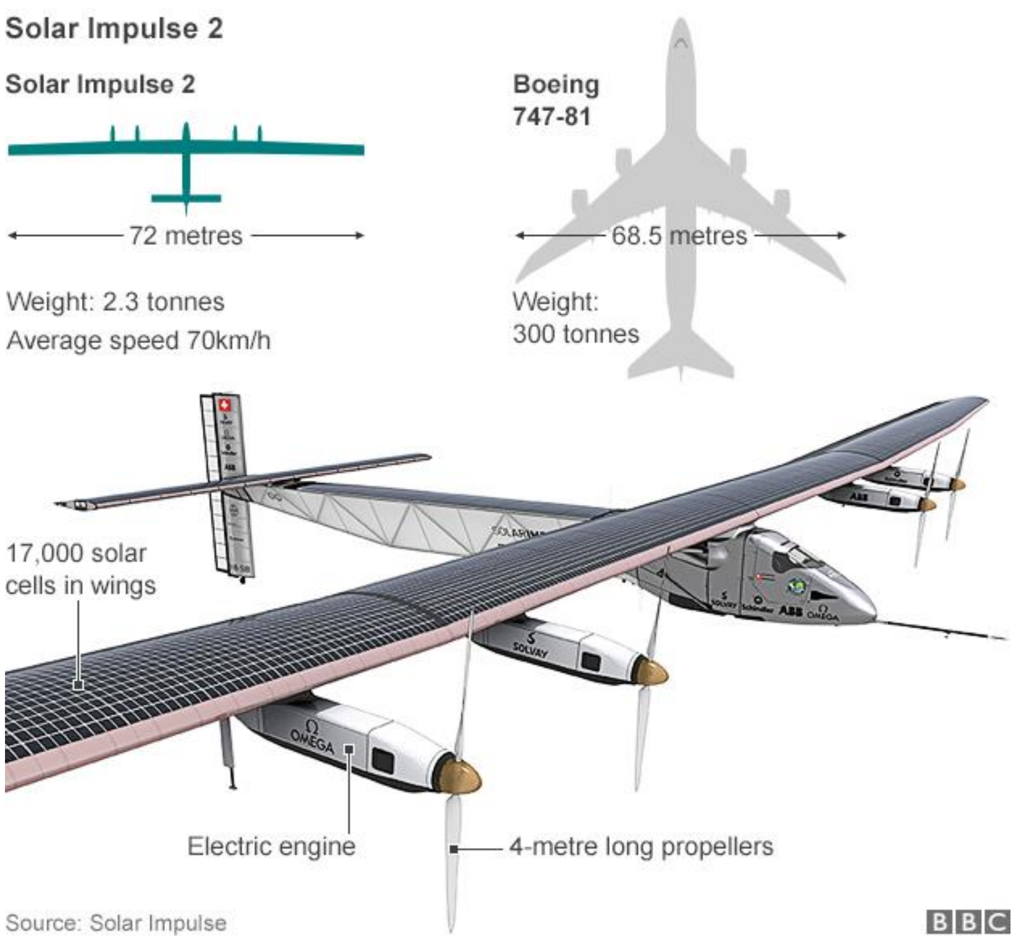
ISS PHOTOGRAPHED BY AN STS-130 CREW MEMBER

International Space Lab
PV panel area 1,632 m²
~130 kW DC power



Solar Impulse on its way from Hawaii to California

Solar Impulse 2



Source: Solar Impulse

- Bertrand Piccard & Andre Borschberg
- 1-seater, 72 m wing span, 2,300 kg weight
- 17,248 back contacted solar cells (22.5% eff, ~60 kW), 270 m², 340 kWh/day
- 4 Li-ion batteries (38,5 kWh each, total weight 633kg) to power the 4 electric motors (13.5 kW/17.5 PS)
- Day light + solar cells → 8,500m → during night + battery → 1,500m
- March 2015: UAE (United Arabic Emirates) → India → China → Japan → Hawaii → 65 km/h, 4500 km, 8600m, San Francisco → New York → North Africa → UAE

Bird‘s eye view to the largest (as of 2013: 290 MW AC) PV plant Agua Caliente in Arizona (2014 ~400 MW)

Source: First Solar

BIPV

Berlin Main Station Overhead glass

Curtain Wall Retrofit

Source: Left: BSW-Solar, right:BISEM 2012

BIPV

Sunways Basel 92 kW BIPV

Thin-film roof tiles

Source:

WHff is member of the scientific/policy board for this project.

Agro – PV pilot plant near Lake of Constance (FhG-ISE/Demeter farm Heggelbach)

Source: FhG-ISE

AGRO - PV

Pilot project FhG-ISE together with Demeter-farm „Heggelbach“ (near Lake Konstanz)

Yield below PV:

Salad	+ 5%
Clover	- 5%
Wheat, celery, potatoes	-18%

Source:

Dual-use PV in Jordan
**** AGRO – PV ****

- ○ **electricity production AND**
  - on same area – agriculture
- ○ **Conversion of arid zones**
- ○ **CO_2-absorption from atmosphere**

Source: H-J Fell Energy Watch Group (12/2016)

Floating PV

...opportunity for bifacial modules!

40 MW floating PV in Huainan (China) by Sungrow Power

~3 MW floating PV in Hyde, Manchester (UK, 2.7 GWh)
12,000 panels, 45,500 m² floating area, 60,000 m² lake

6.3 MW floating PV in London,
Queen Elizabeth Reservoir (5.8 GWh)

Commercial roof-top (2.2 MW) in Arizona on warehouse from REI (Recreational Equipment, Inc), located in Phoenix

PV and ST roof top at my home since 1993

Source: Winfried Hoffmann

- Why did the „Grid connected“ market segment grow so much?
- The answer is: market support programs were the reason!
- Why should a product/market segment be supported?
- Liberal market ideas are against such a support „…the market makes it rightly!“
- … in modern societies we must distinguish between two very different kinds of products: consumer products and strategic products, which have to be treated differently!

Source:

Different Products and Services Need Different Support Mechanisms

Consumer Goods **like**

 # mobiles
 # laptops
 # FPD television
 # automobiles and many more

only need a global fair trade: customers *want* the new product!

Strategic Goods **like**

 # the way electricity is produced
 # the way transportation is done
 # the way people are living in the urban environment

do need **initial political and public support**

Source: Own ideas

Boundary Conditions for *Strategic Products*

Electricity

\# 40 years ago the worldwide support for nuclear energy
\# 20 years ago environmental investments to extract NOx, SOx
\# todays concerns on climate change (CO2), price development and security of supply

Automotive

\# 10 years ago introduction of catalyst
\# todays consideration on electromobility (...with RE!)

Urban living

\# energy passport of buildings (eg new EU building directive)

Source: Own ideas

Need for and Type of Support Programs

Within the afore mentioned *Strategic Goods* for a society there are established technologies at a given cost and price level – one cannot distinguish where the product – like electricity - is coming from!

New technologies (like RE (PV)) have in the beginning always a high cost (and price) which will only go down if they can develop a large volume (*Price Experience Curves*) to drive down cost and price

Only *market pull* (with appropriate R&D support) will enable the needed cost and price decline, not a *technology push* by its own

Support programs based on market pull should be and have:
 # easy and simple # no stop and go # integrate private capital
 # create a highly competitive market place

Source: Own ideas

Feed in Tariff (FiT) as *best market pull* support for RE in the electricity sector

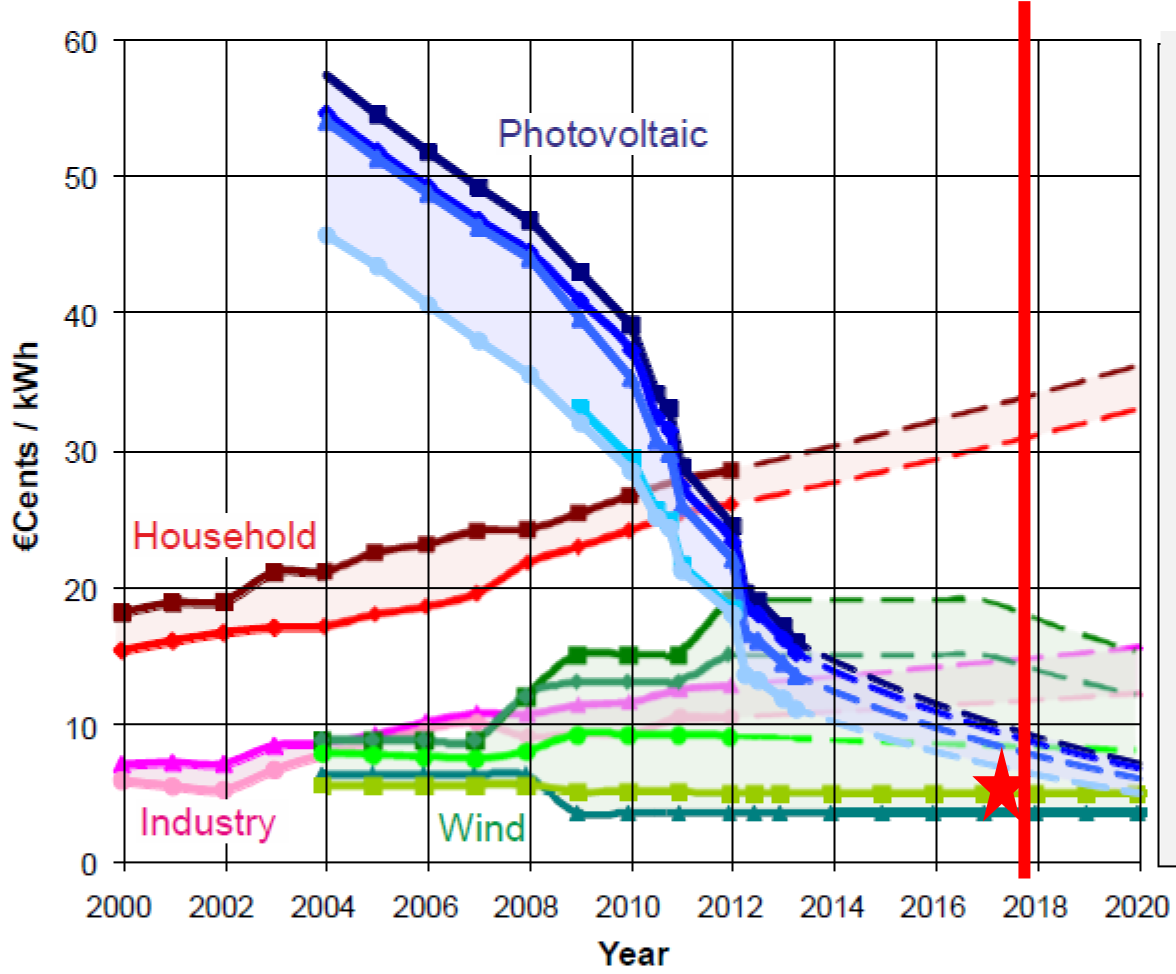
The FiT budget is used to pay *private investors* (eg home owners, companies, utilities) a tariff for each RE kWh

Based on a CoO calculation for the produced RE kWh (which is different for each respective RE technology) over the lifetime of the investment (typically 20 years) the investor gets a reimbursement including a fair (6-8% ROI) profit margin of his investment

The FiT budget should be distributed most easily to all electricity users in a country (with an exemption of those industries who are dependent on lowest electricity prices, like chemical-, Al-, and semiconductor industries) and not be taken from an annual public budget from a ministry

Source: Own ideas

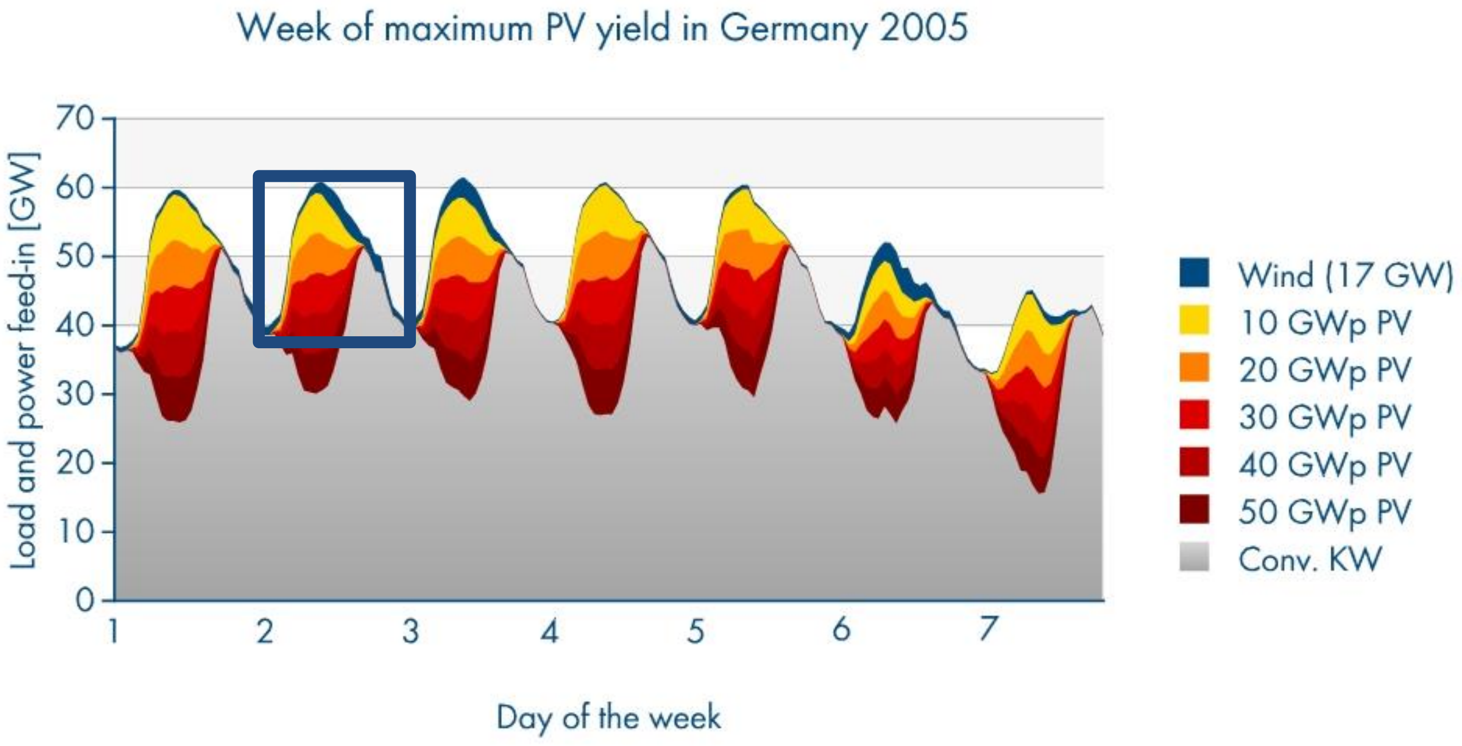
Strompreis (Haushalt & Industrie) & EEG (~>Kosten) in Deutschland: „Wasserfall“



Source: BMWi, FhG-ISE

Aktuelle ppa‘s in Deutschland für ausgeschriebene Freiflächenanlagen

Impact on Germany‘s electricity load curve with up to 50 GW PV



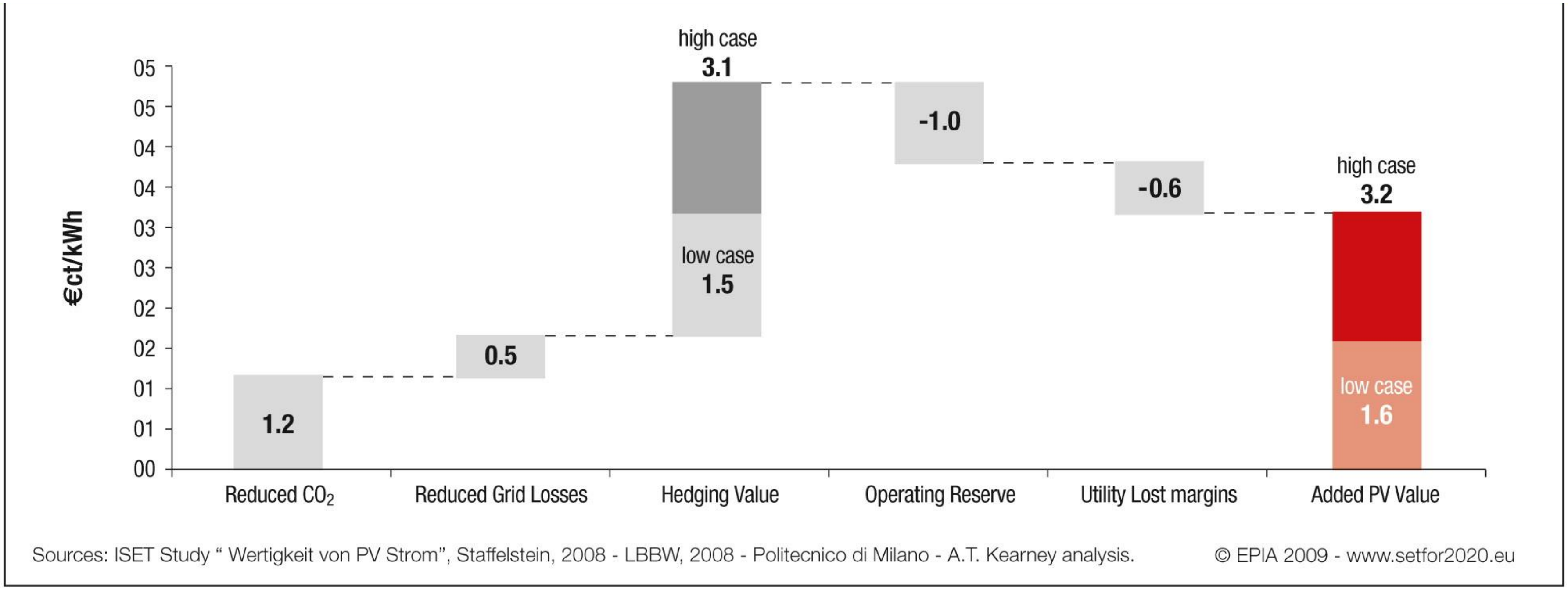
- PV reduces the daily peaks

Do the >100 billions € FIT money pay off for a society like Germany?

Trade-off for the often discussed
„Wälzungssumme“
(= total budget for the feed-in tariff – induced support money
versus
the benefit for the society –
characterized over 20 years (FIT time)
@30 years life time even more!

Source: Winfried Hoffmann

Net value adding characteristics of PV-generated electricity (in €ct/kWh)



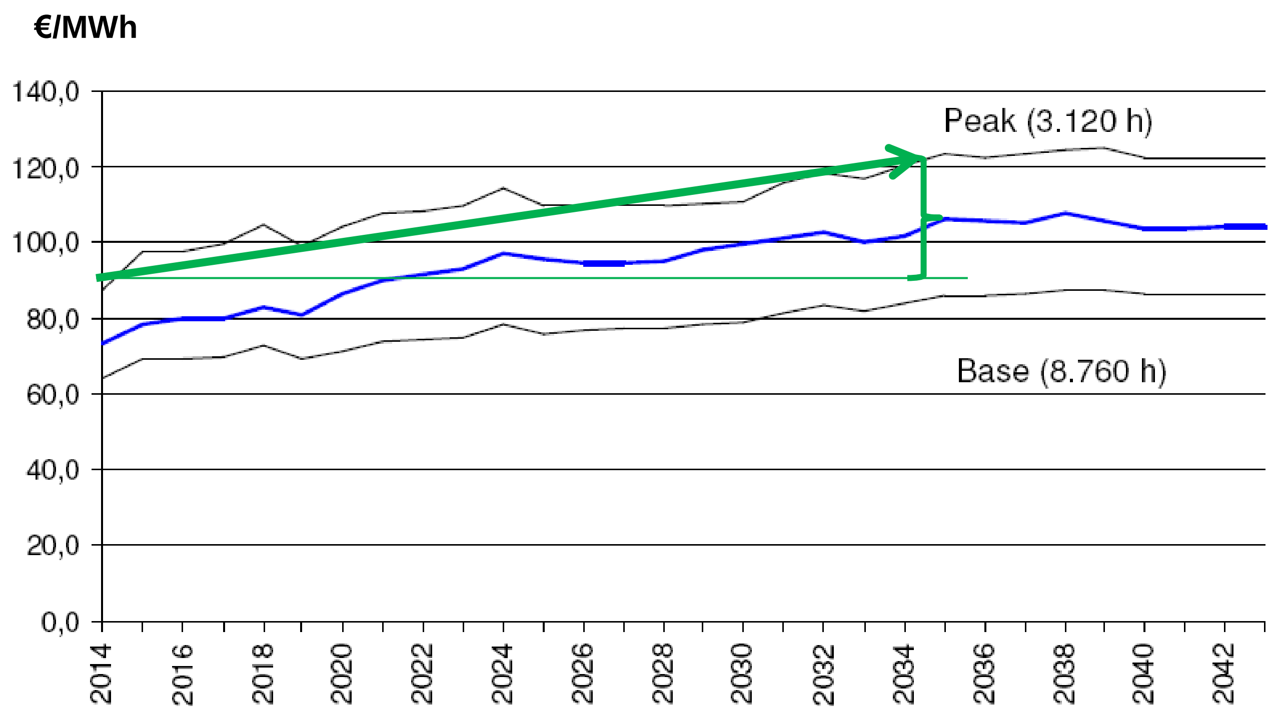
Sources: ISET Study " Wertigkeit von PV Strom", Staffelstein, 2008 - LBBW, 2008 - Politecnico di Milano - A.T. Kearney analysis.

© EPIA 2009 - www.setfor2020.eu

@ 30 €/
t CO_2

@ 3 – 6 €ct/kWh
price increase in
20 years

Projection of electricity market prices in x €/MWh (=0.1x €ct/kWh)



3€ct /kWh in 20 years (=1.4% p.a.)

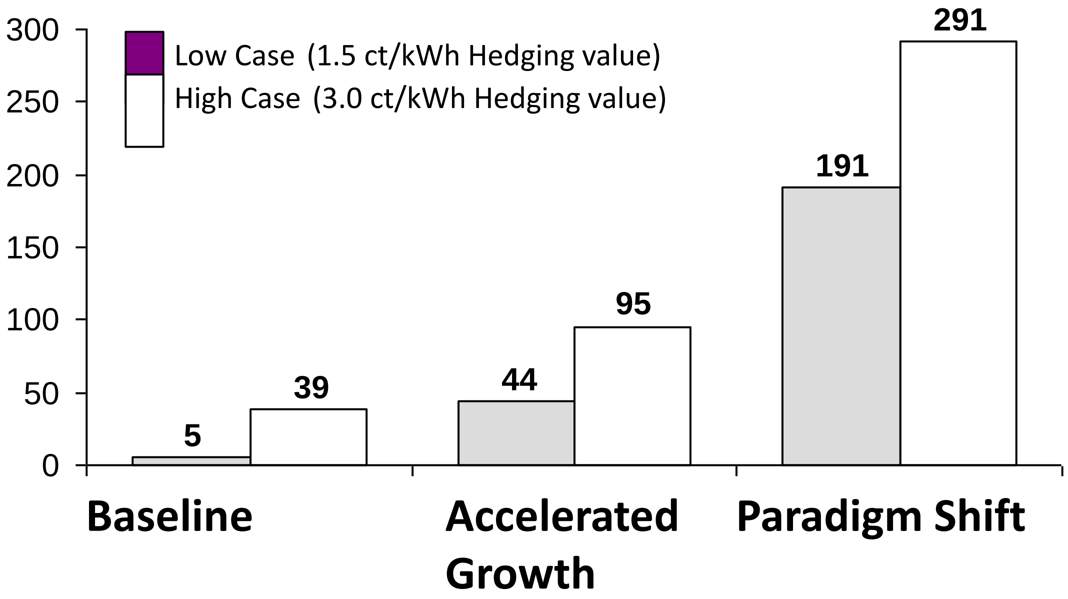
Past 12 years: ~5%p.a. increase → x 2 in 20a

Hedging value would be 3 €ct/kWh (!!)

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



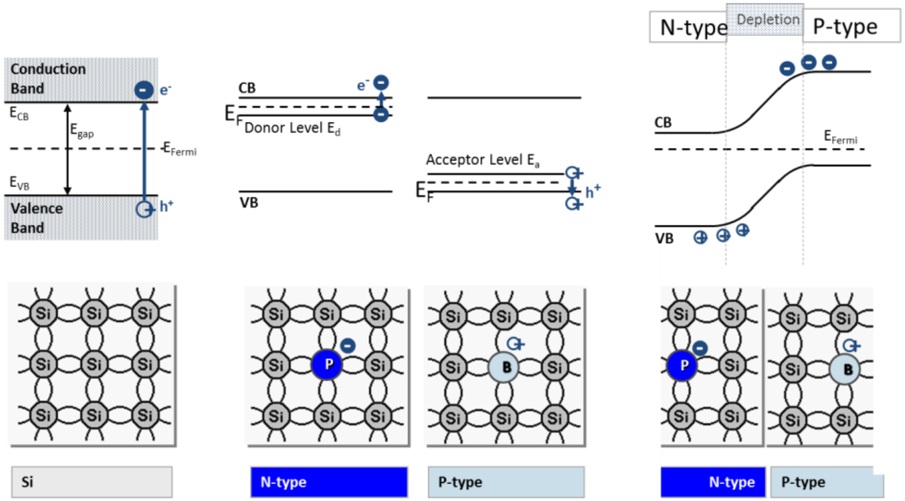
155 182 235

€ billion **FiT investment needed in absolute values**

Physics & Technology

PV physics – c-Si and Thin-Film

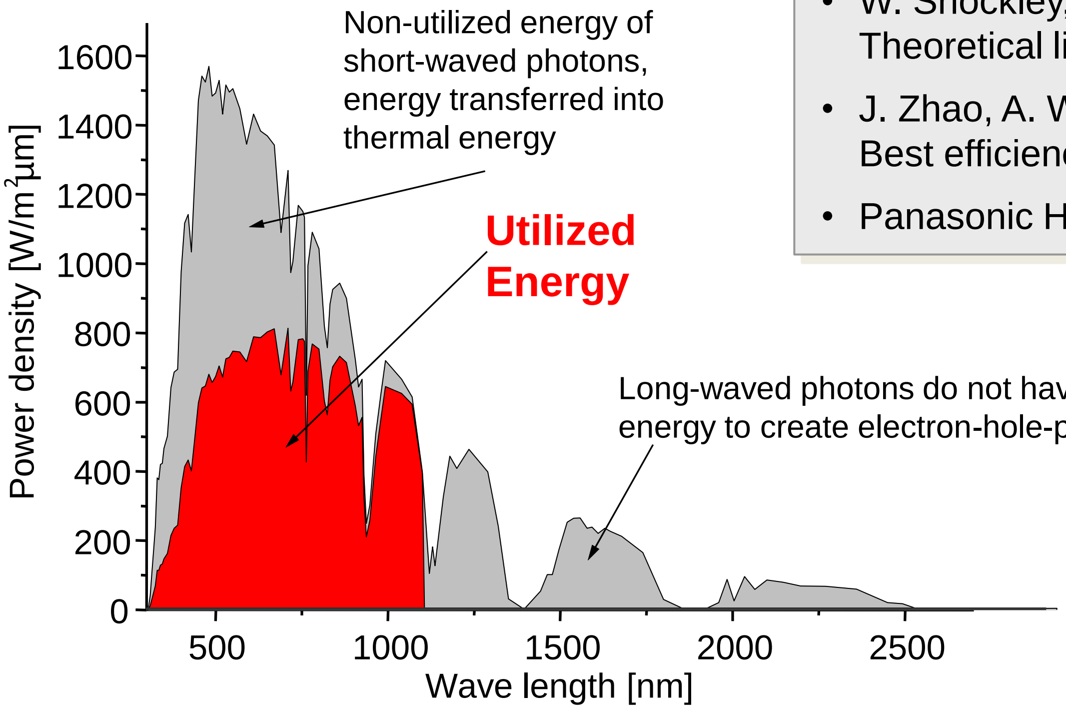
+ Dye cells + OPV



PV industry for c-Si, Thin-Film and new technologies

Maximum Efficiency of Semiconductors

Solar Cells based on one pn-Junction



Non-utilized energy of short-waved photons, energy transferred into thermal energy

Utilized Energy

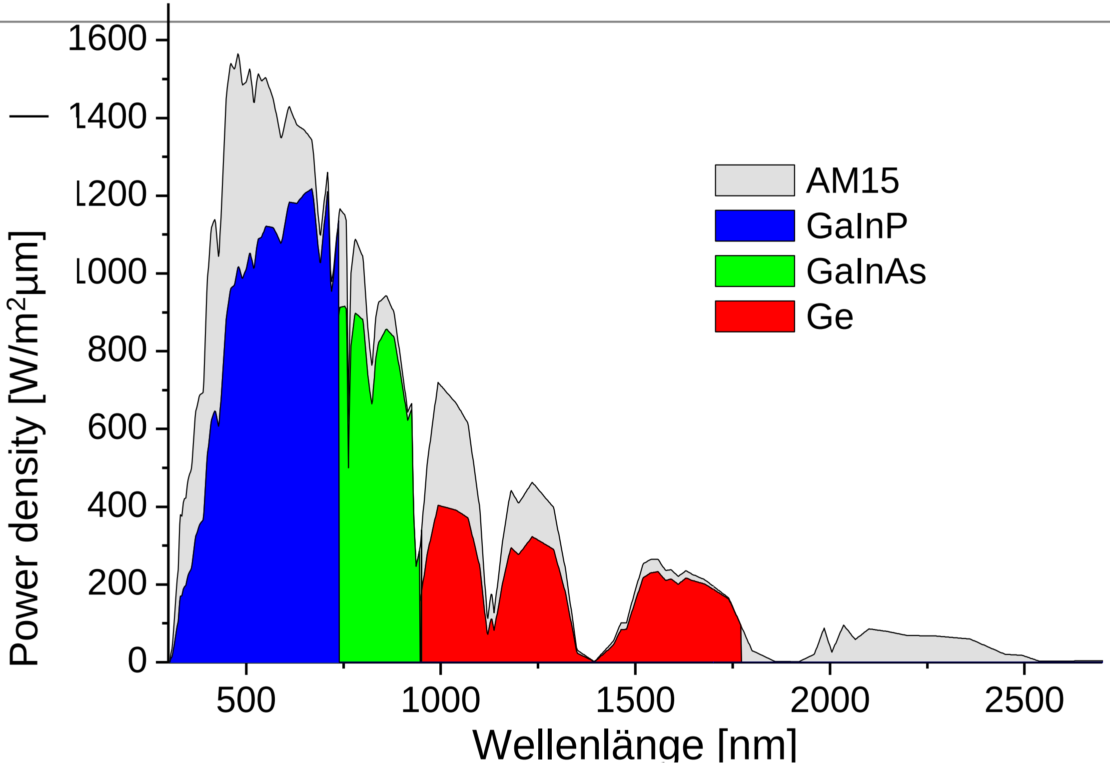
Long-waved photons do not have enough energy to create electron-hole-pairs

Source: Fraunhofer Institut Solare Energiesysteme

- W. Shockley,H.-J. Queisser (1961): Theoretical limit 33%
- J. Zhao, A. Wang, M.A. Green (1999): Best efficiency in laboratory 24,7%
- Panasonic HIT (2014) 25.6%

Multi Junction Solar Cells

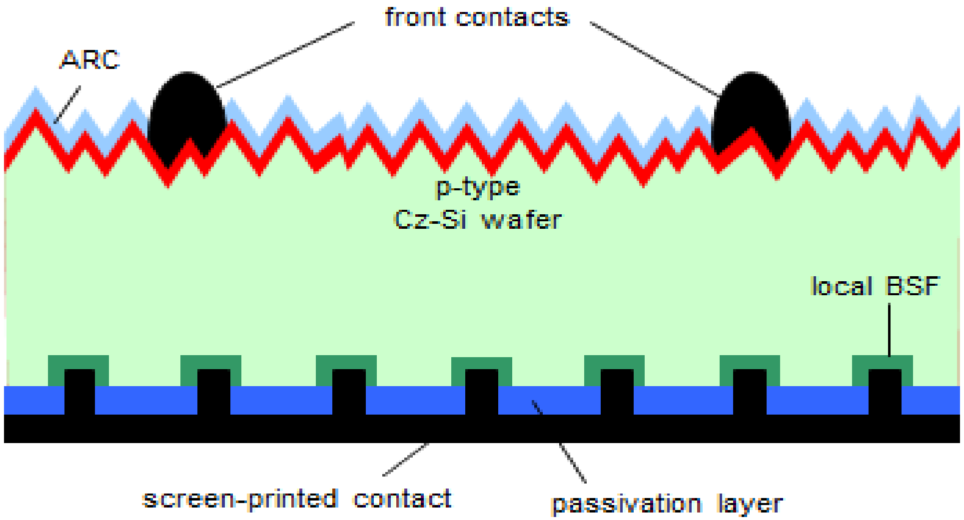
Combine Materials with Different Absorbance Behaviour



Wave length [nm]

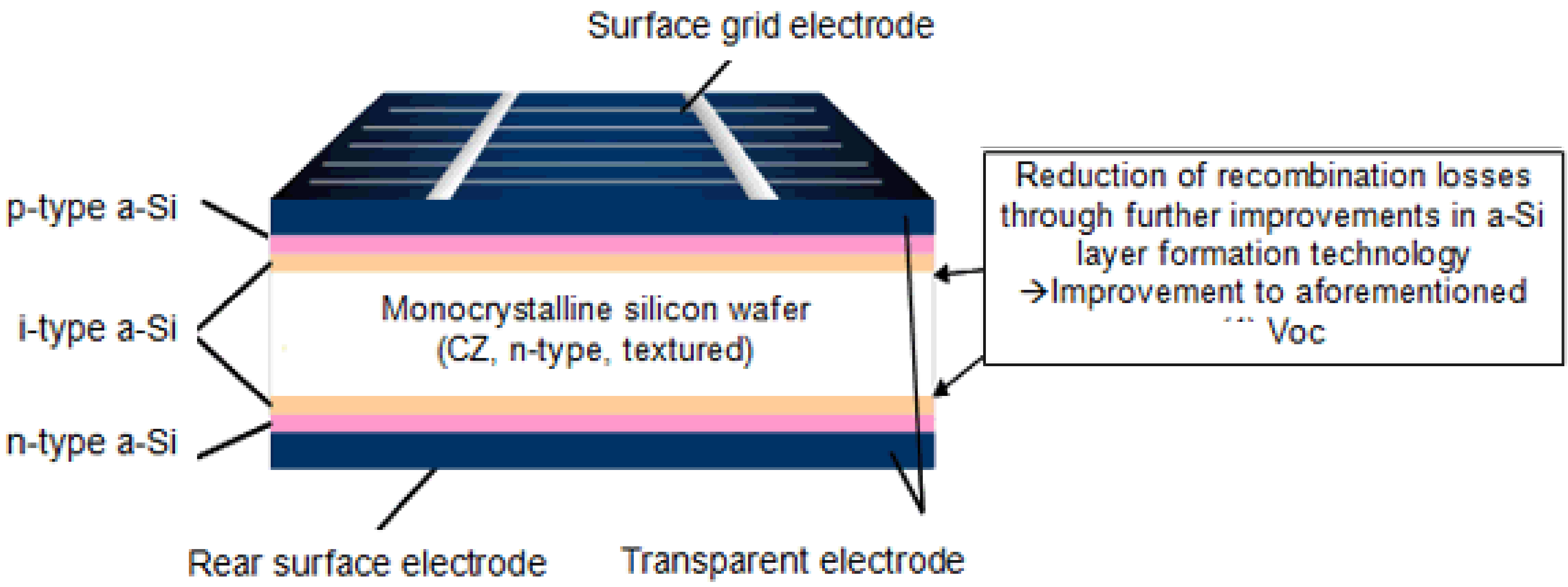
Quelle: **Fraunhofer** Institut Solare Energiesysteme

All-screen-printed solar cell with eta >20% with standard 156 mm Cz-wafers



Source: A. Metz et al., SCHOTT Solar

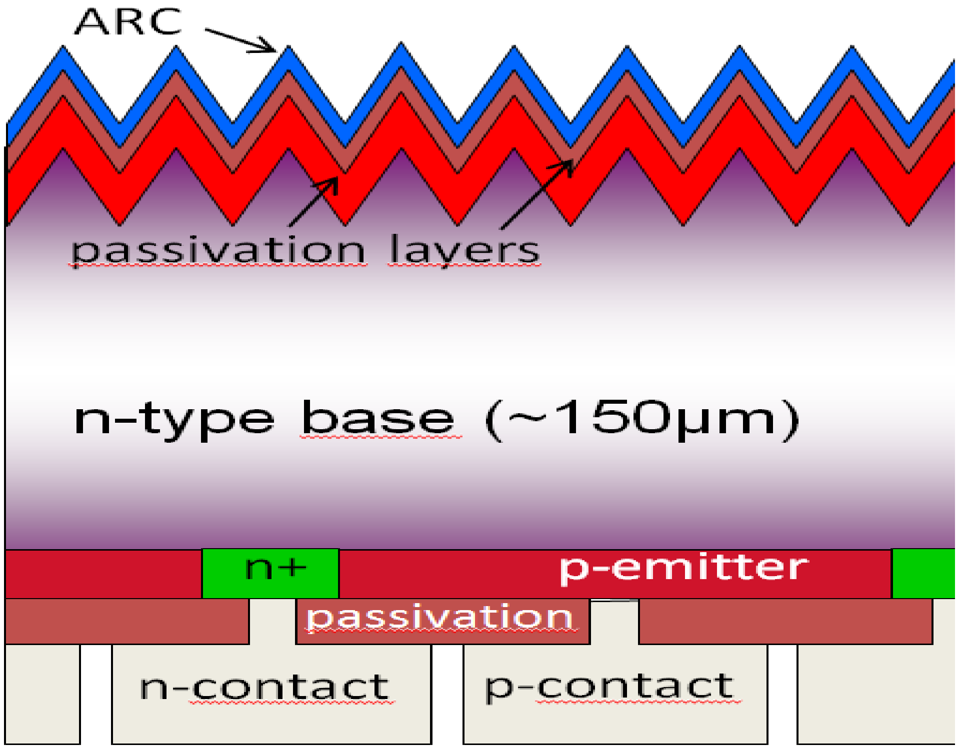
„Honey moon“ HJ cell
Panasonic world record 25.6% eff



Reduction of recombination losses through further improvements in a-Si layer formation technology
→Improvement to aforementioned ··· Voc

Source: Panasonic

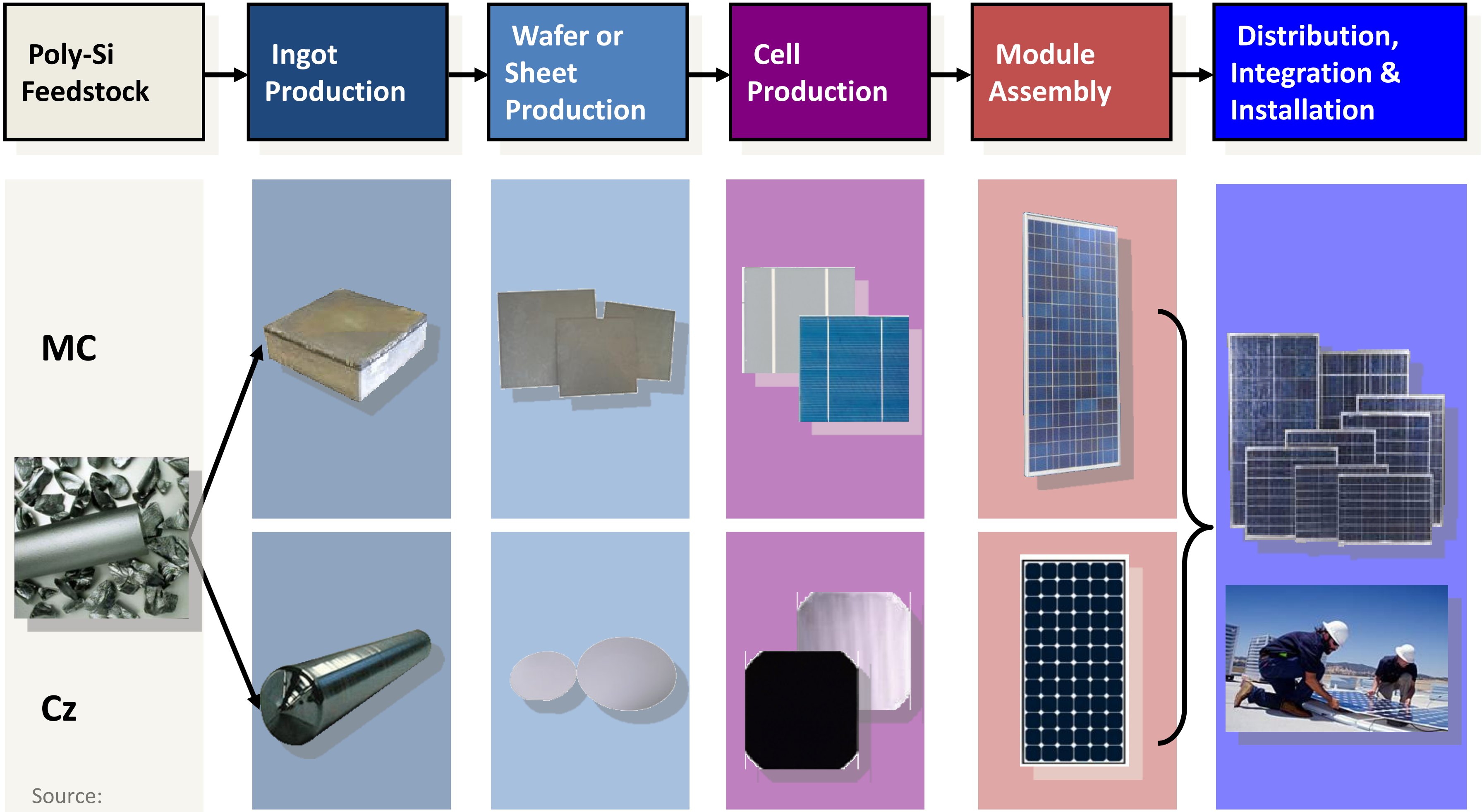
Back-contacted solar cells for highest c-Si efficiencies > 23% in production



Sun Power technology – rather expensive

New opportunities – Ion implanters (machines yet too expensive)

Crystalline Silicon PV ModuleValue Chain



Poly-Si Feedstock → **Ingot Production** → **Wafer or Sheet Production** → **Cell Production** → **Module Assembly** → **Distribution, Integration & Installation**

MC

Cz

Source:

Investments

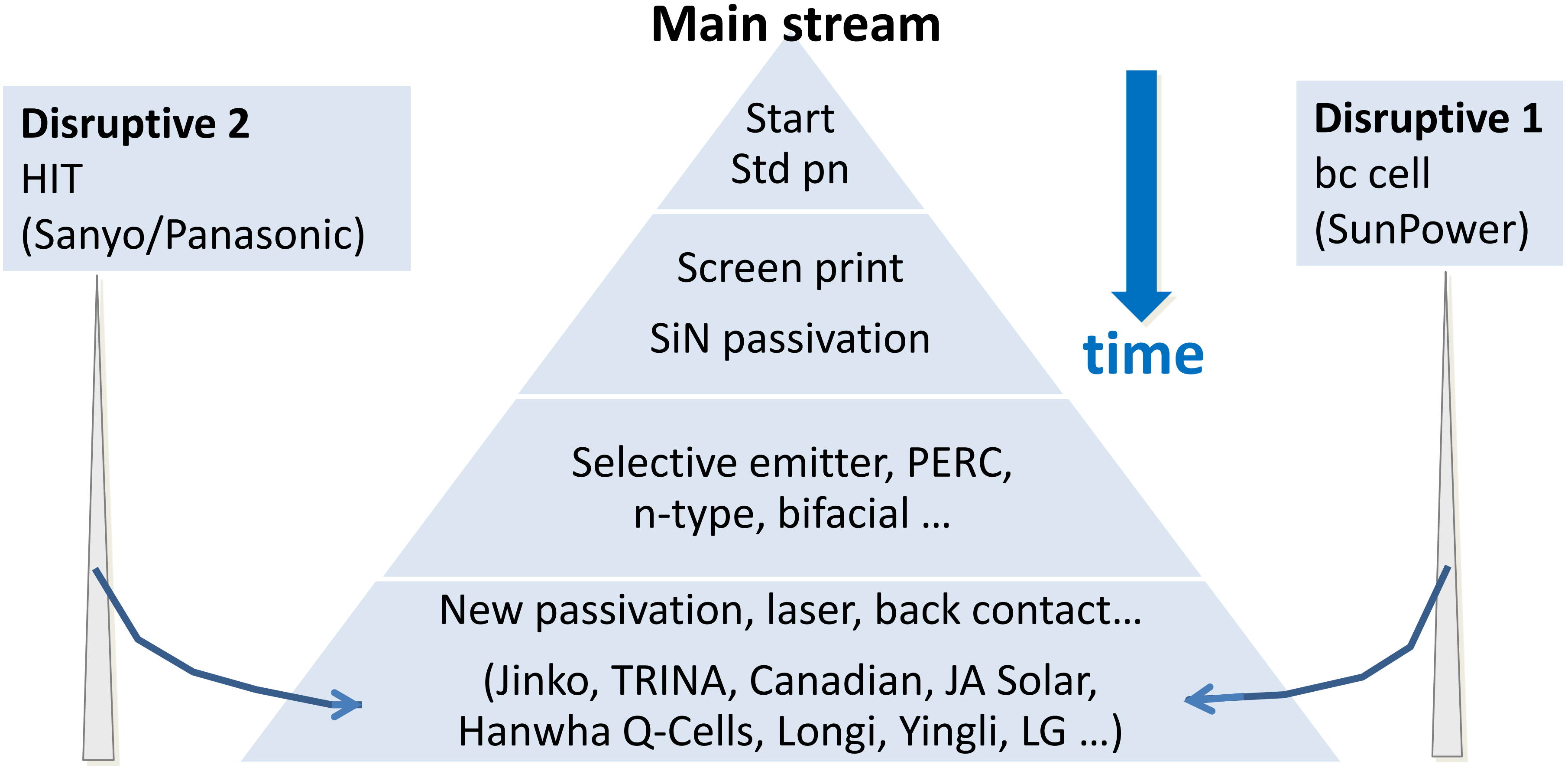
Value Chain Crystalline Si-Modules

Investments	Mio € per 1 GW	
Si feed stock	300	600 … 1,200
Wafer	300	600 … 800
Cells	150	300 … 500
Modules	150	200 … 400
total	**900**	**1,700 …2,900**

today (2018) even less ← 2010 … 2005 … 2000

Source: Own estimates

Main stream versus disruptive cell technology



Main stream

Disruptive 2
HIT
(Sanyo/Panasonic)

Start
Std pn

Screen print

SiN passivation

Selective emitter, PERC,
n-type, bifacial …

New passivation, laser, back contact…

(Jinko, TRINA, Canadian, JA Solar,
Hanwha Q-Cells, Longi, Yingli, LG …)

time

Disruptive 1
bc cell
(SunPower)

Ca 1 GW

2010 cumulative experience ca 30 GW

Ca 1 GW

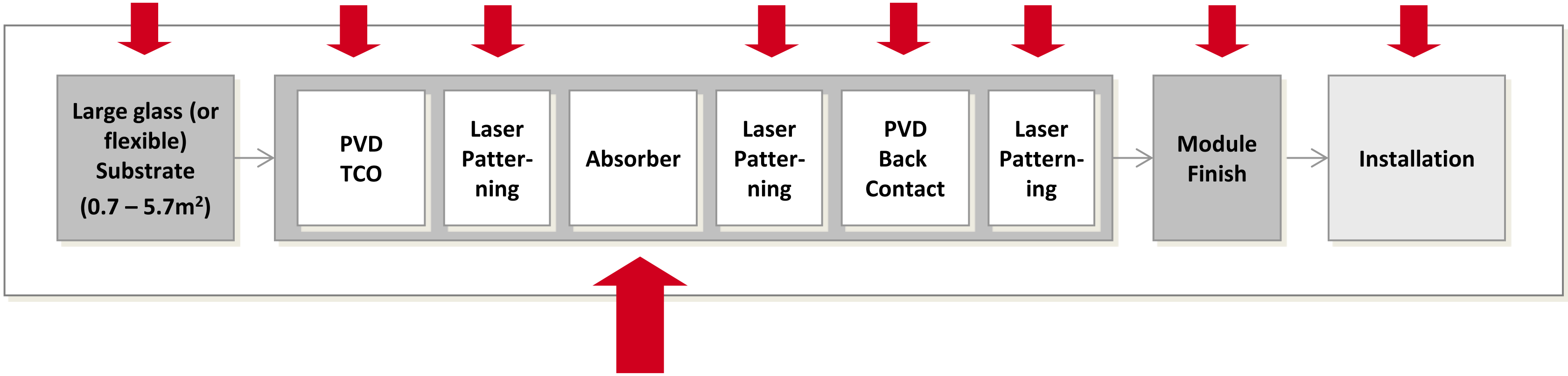
Lightweight and flexible solar modules need Thin-Film products!

Deposition of µm-layers on
steel or plastic foil
…glass is possible also!

Source:

Thin Film PV Value Chain

Same/similar process steps with same/similar cost / m²



Thin Film a-Silicon PECVD a-Si and µc-Si (6 ... 10 → **7 ... 12**)

CIGS co-evaporation (10 ... 12 → **15 ...17**)

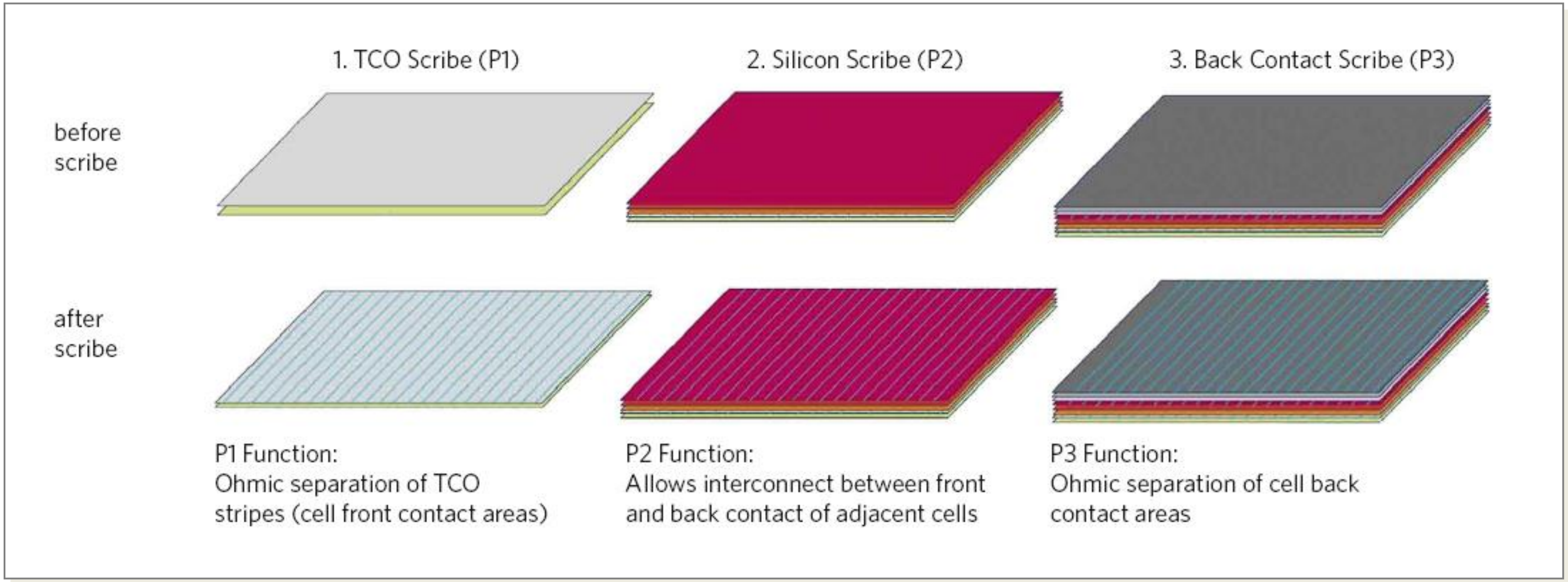
Sputtering and selenization (9 ...11 → **15 - 17**)

CdTe/CdS close space sublimation (9 ... 11 → **15 - 17**)

Different processes and material cost for absorber formation

Interconnection

3 Scribing Steps



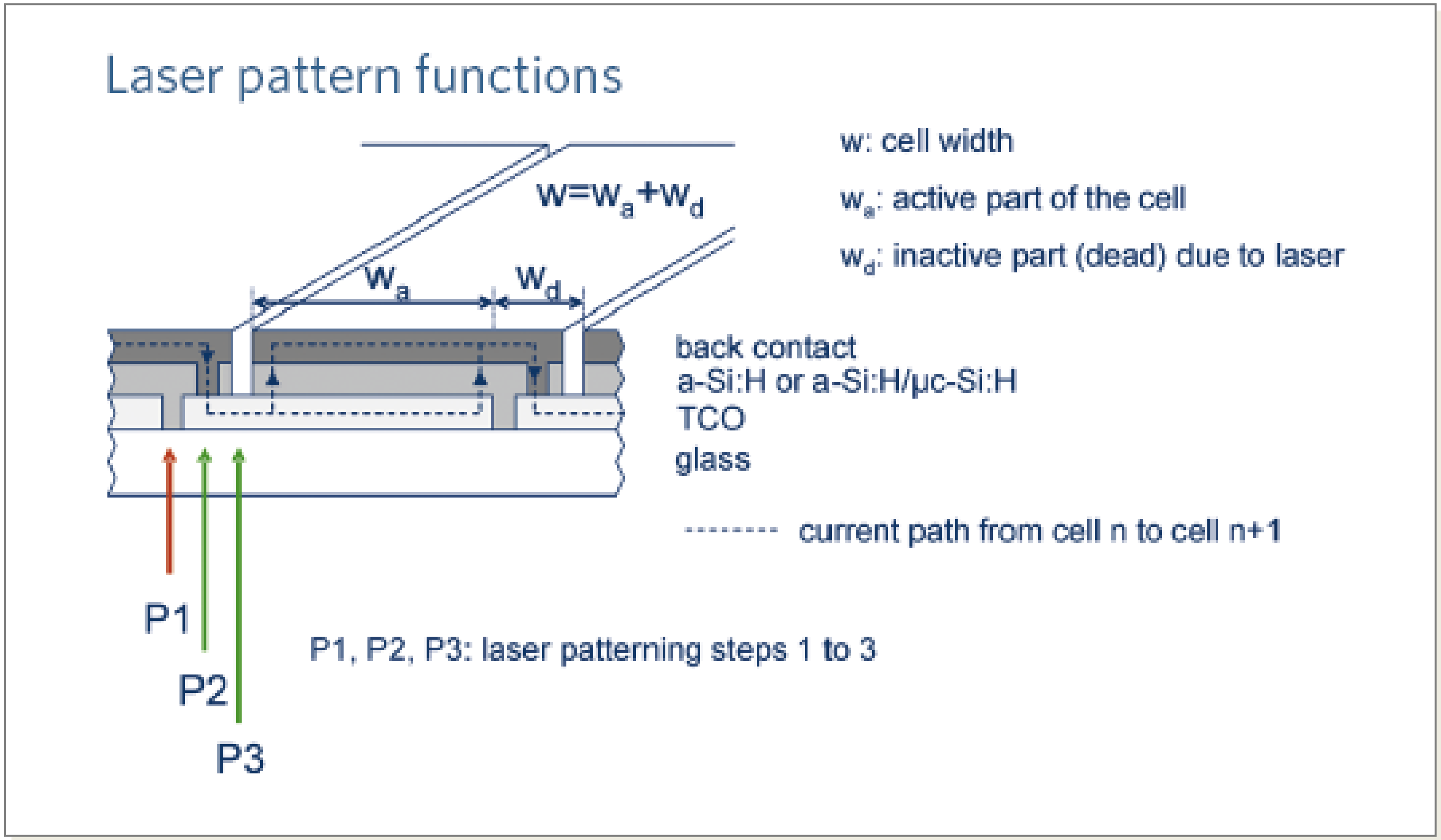
P1 Function:
Ohmic separation of TCO stripes (cell front contact areas)

P2 Function:
Allows interconnect between front and back contact of adjacent cells

P3 Function:
Ohmic separation of cell back contact areas

Interconnection

Schematics



Laser pattern functions

w: cell width

w_a: active part of the cell

w_d: inactive part (dead) due to laser

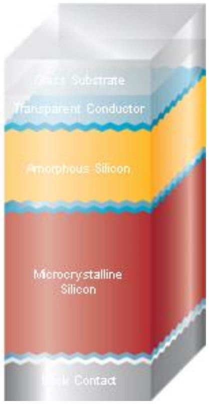
back contact
a-Si:H or a-Si:H/µc-Si:H
TCO
glass

-------- current path from cell n to cell n+1

P1, P2, P3: laser patterning steps 1 to 3

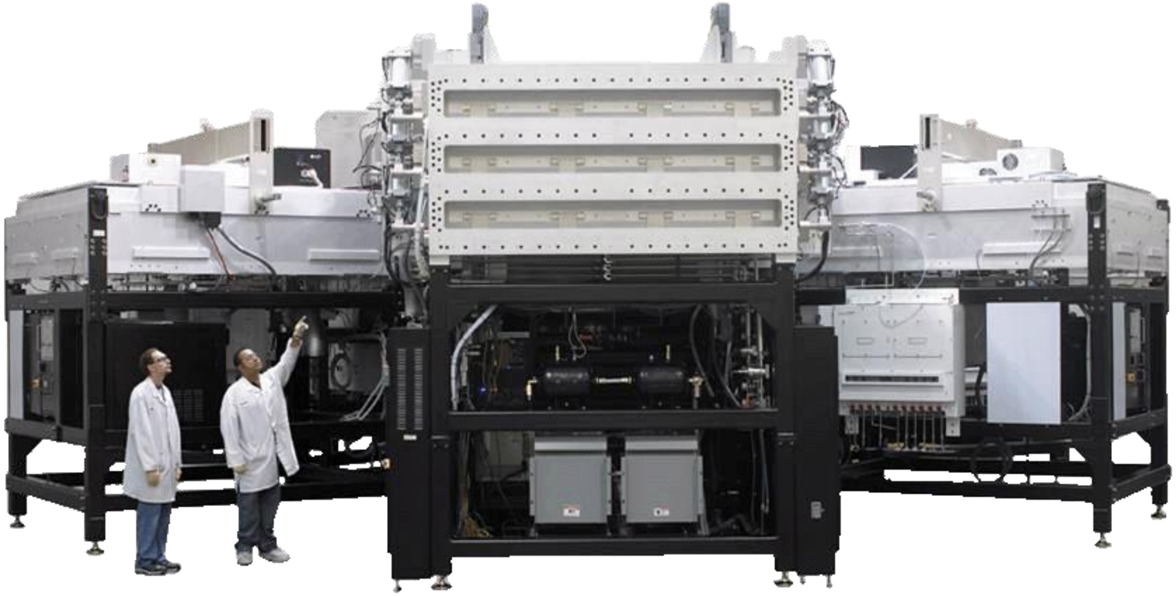
Layer Deposition

PECVD on Superstrate



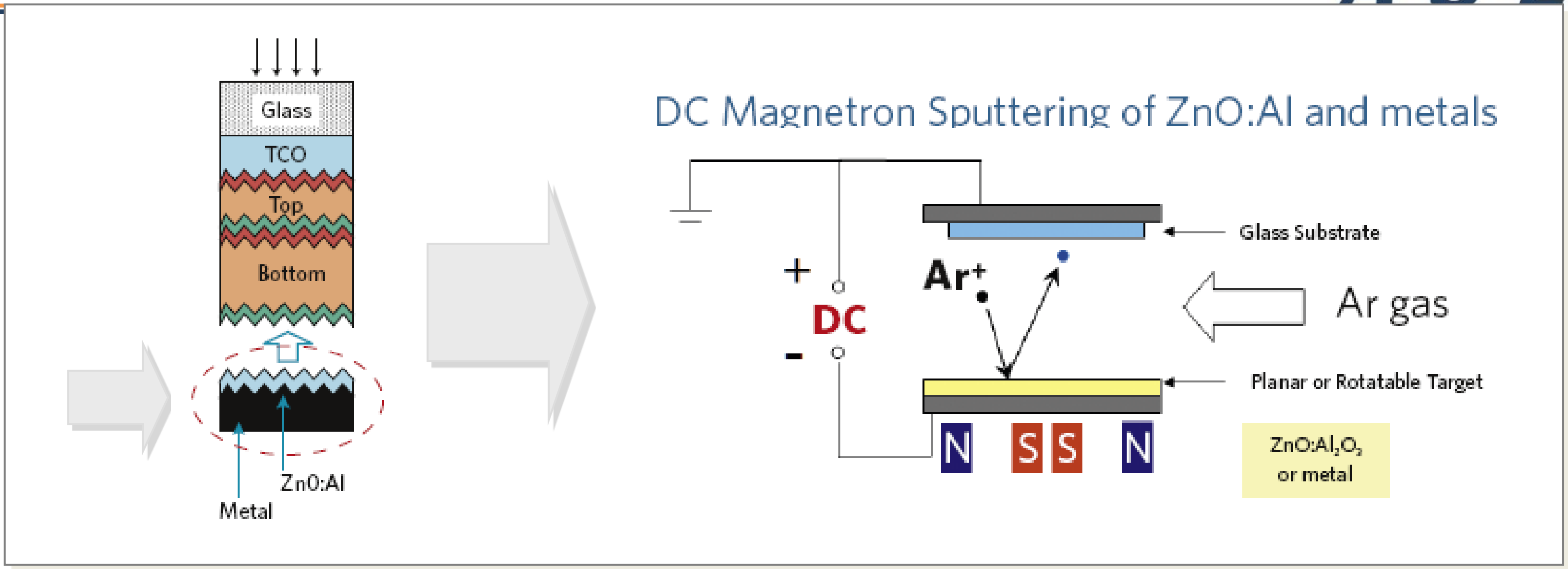
a-Si:H / µc-Si:H Tandem Cell

Applied SunFab™
Gen 8.5 PECVD System

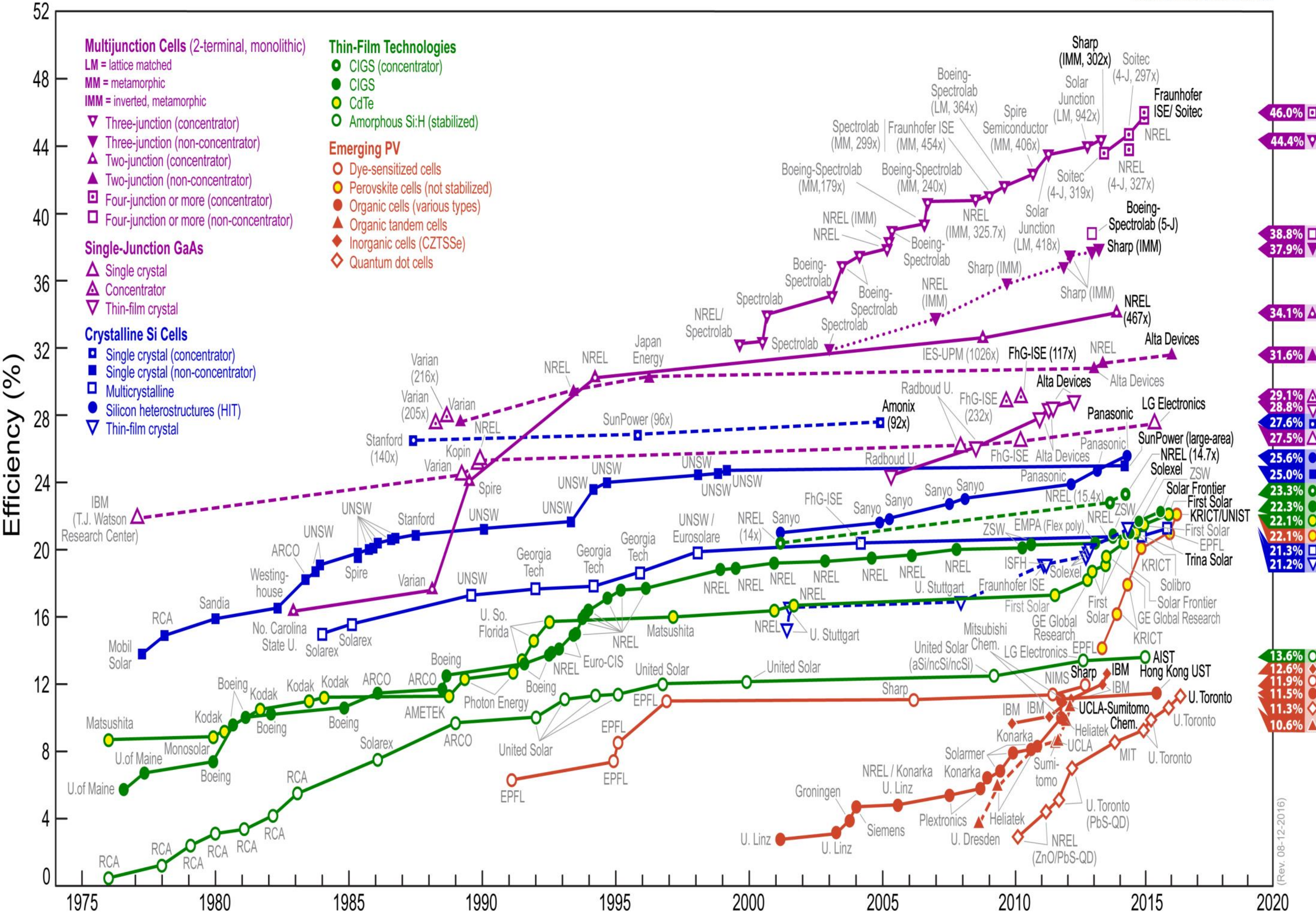


Back Contact

Contact and Optical Mirror

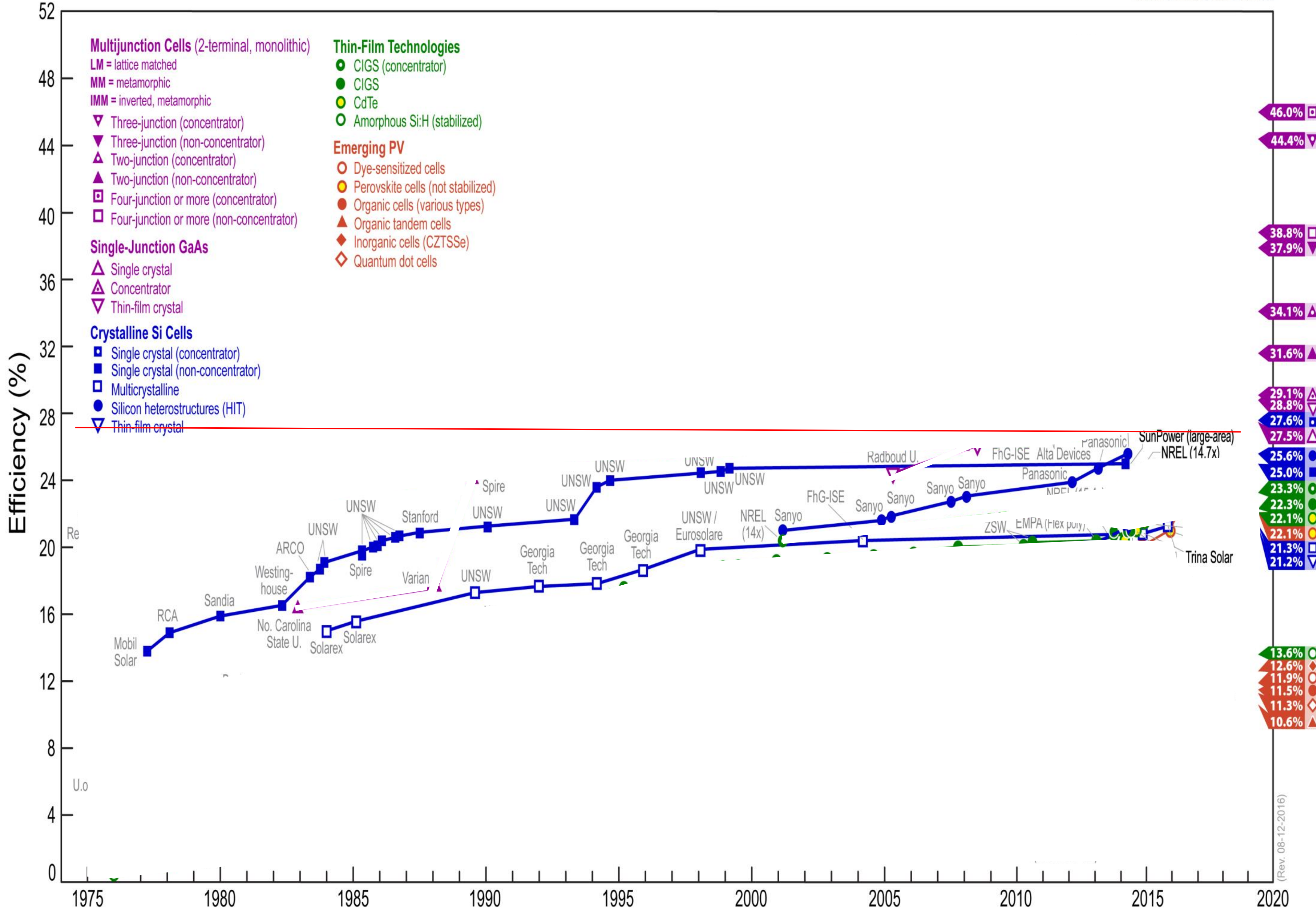


Best Research-Cell Efficiencies

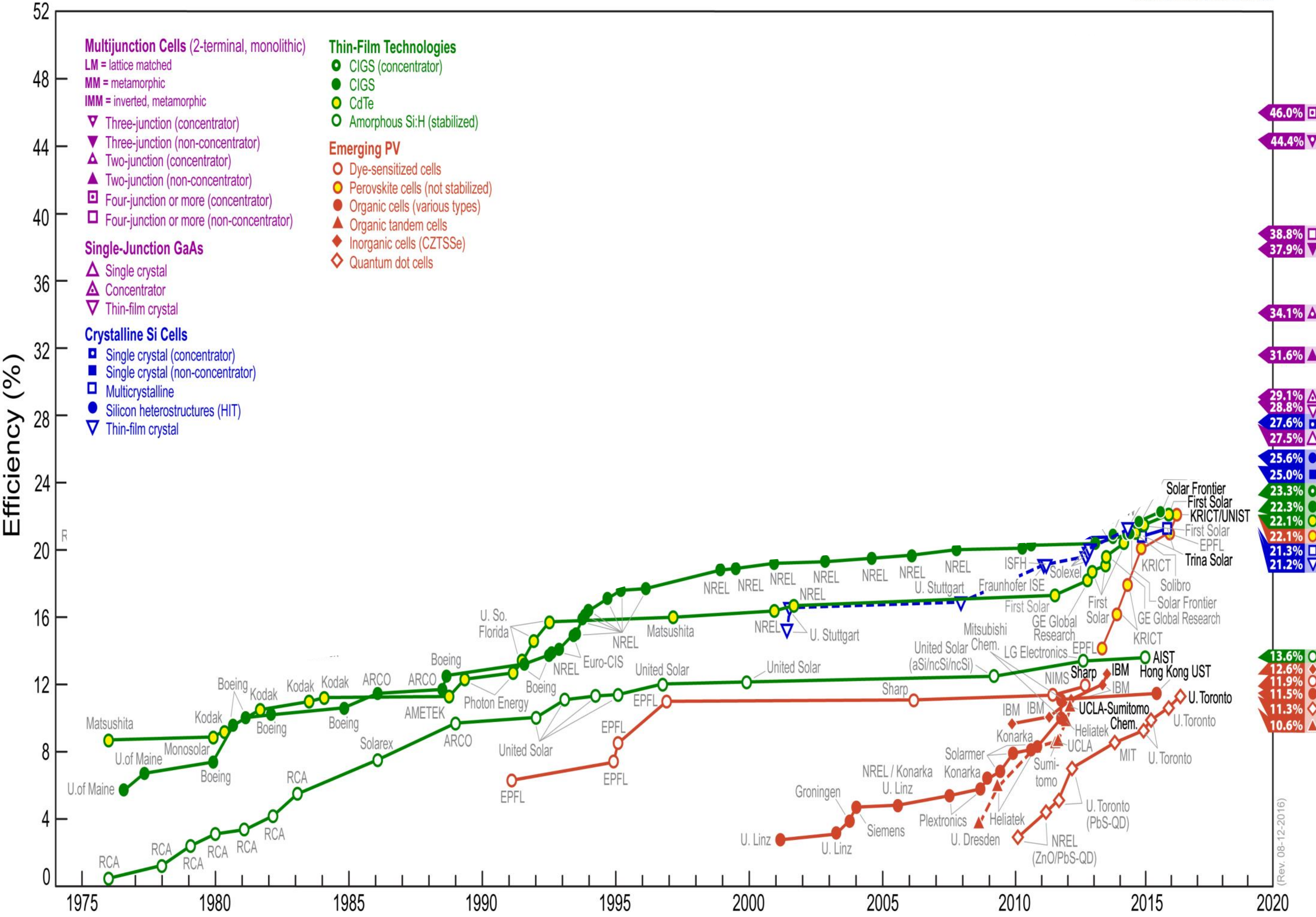


Best Research-Cell Efficiencies

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



Best Research-Cell Efficiencies



Best Research-Cell Efficiencies

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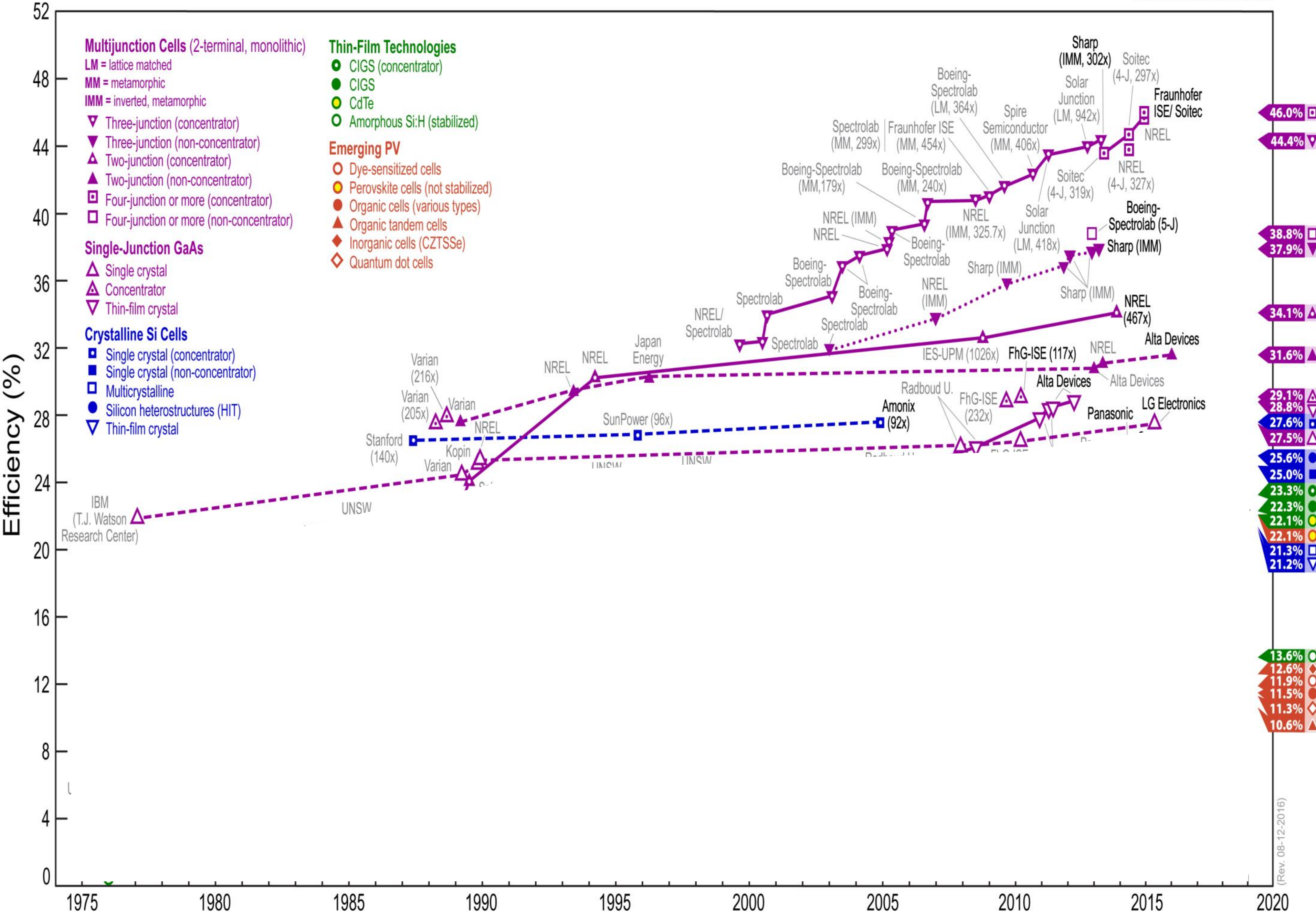
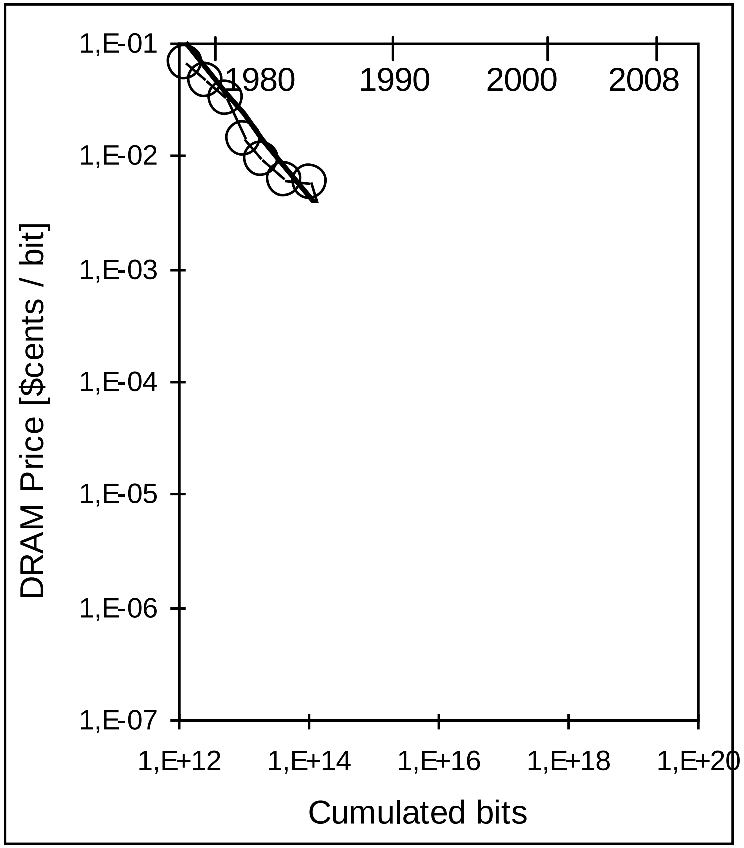


Die erstaunliche Vorhersagekraft
von
Preis-Erfahrungs-Kurven

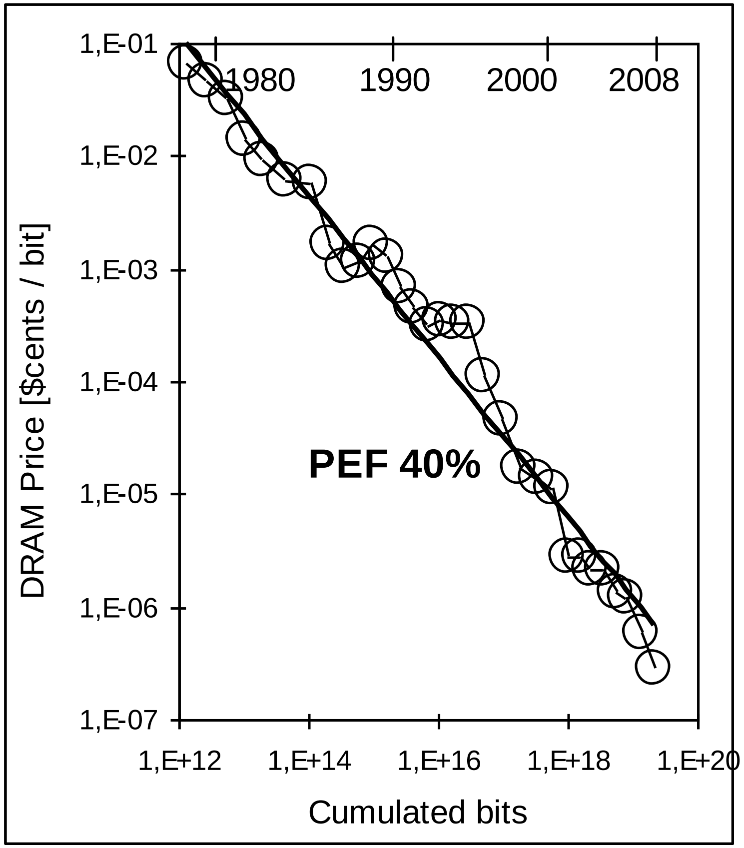
Source:

DRAM – Moore´s Law

Experience Curve



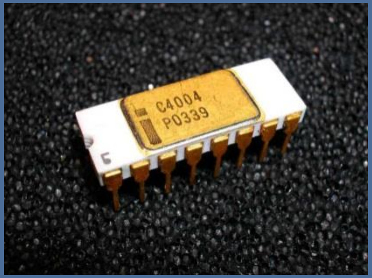
Experience Curve



Source: Applied Materials, Semiconductors Group, 2009

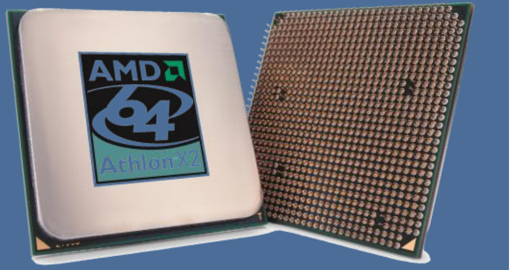
Semiconductor – Tremendous Development

1971

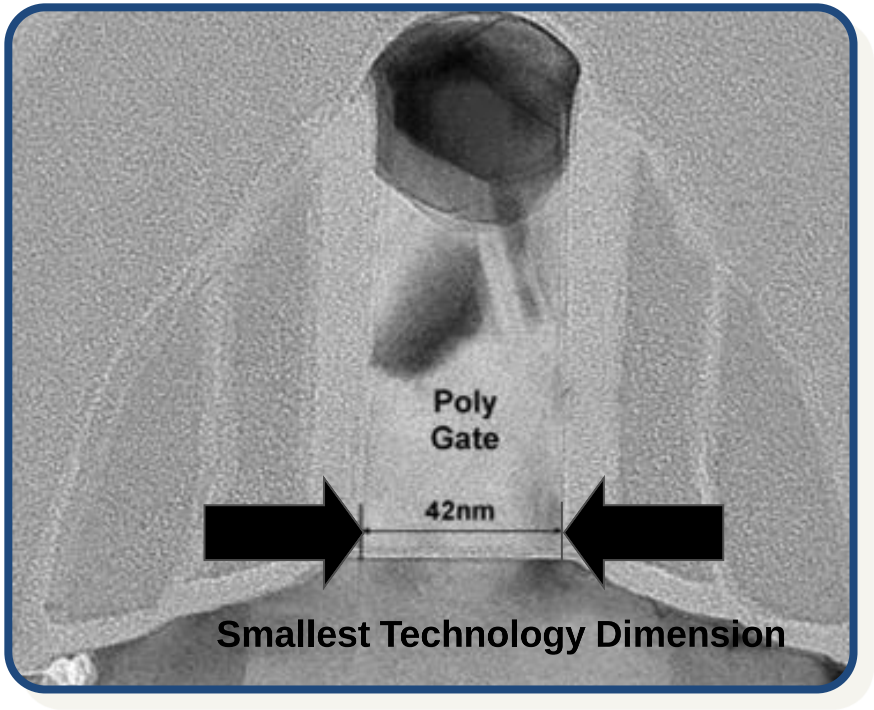


4 bit Microprocessor, Intel, 1971

Today



State-of the Art Microprocessor, AMD, since 2005

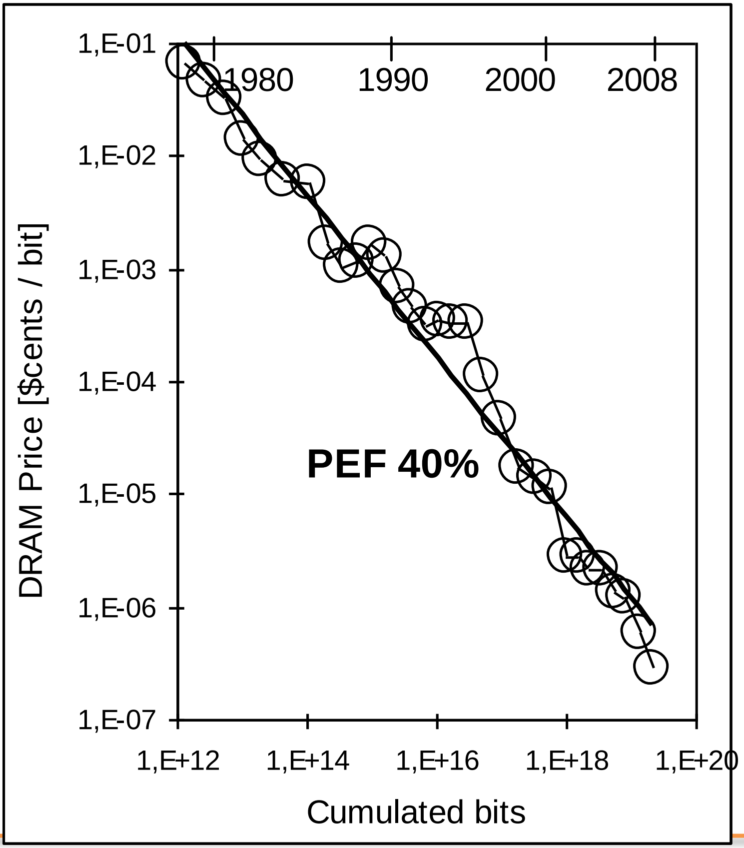


AMD PMOS transistor with
physical gate length of 42nm

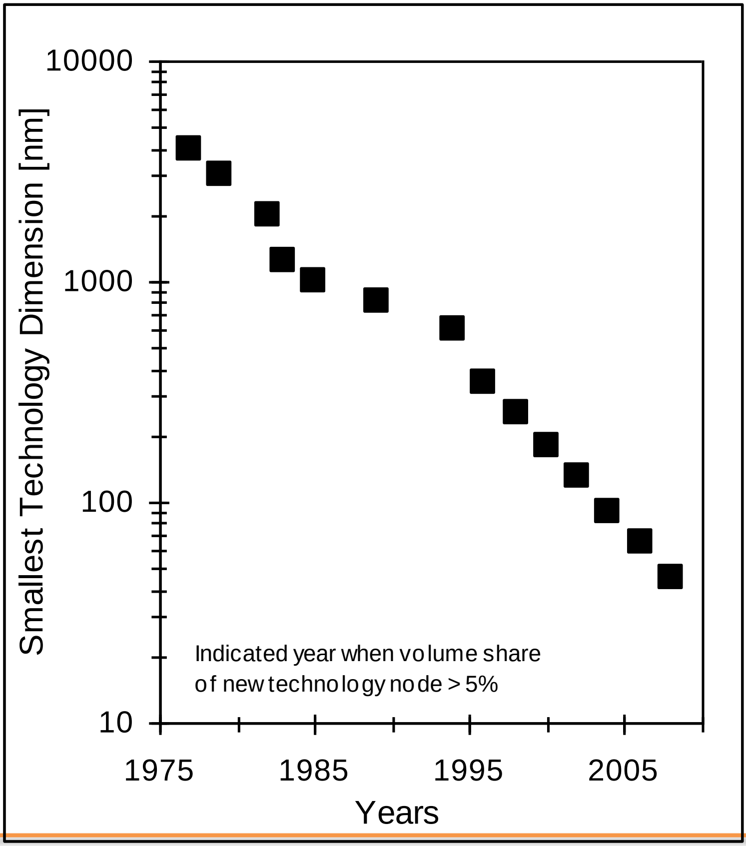
Source: Semiconductor Insights Inc.

DRAM – Moore´s Law

Experience Curve



Driven by Technology



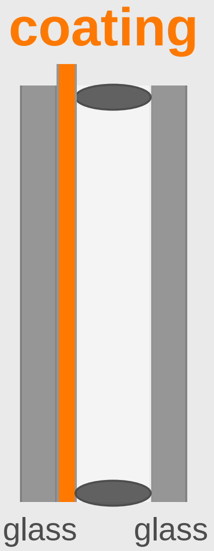
Indicated year when volume share of new technology node > 5%

Source: Applied Materials, Semiconductors Group

Architectural Glass

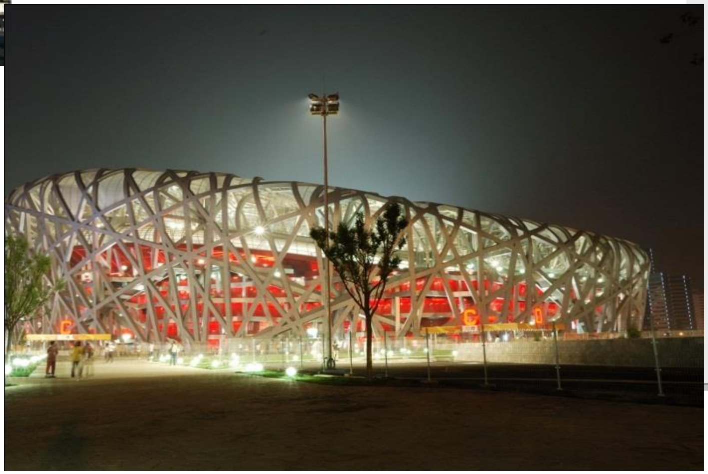
Atlantic Hotel Sail City,
Bremerhaven, Germany

Baltimore Visitor Center
Baltimore, MD USA



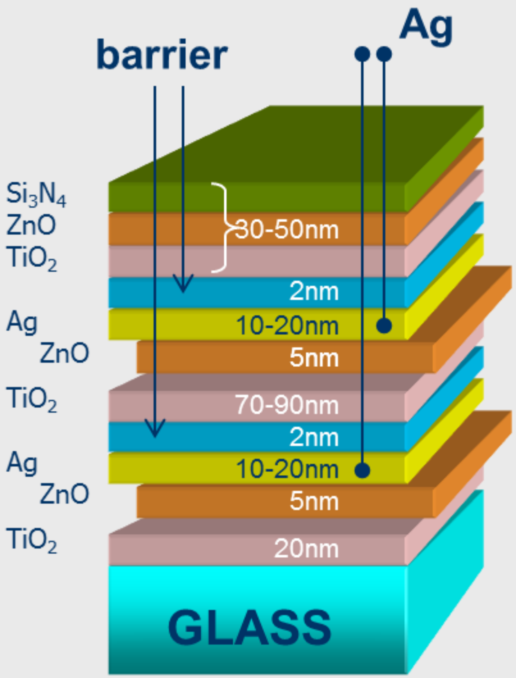
**~ 500 million m2
coated glass p.a.**

Bird’s Nest Stadium,
Beijing PRC



Low-e Coatings

Double Ag Layer



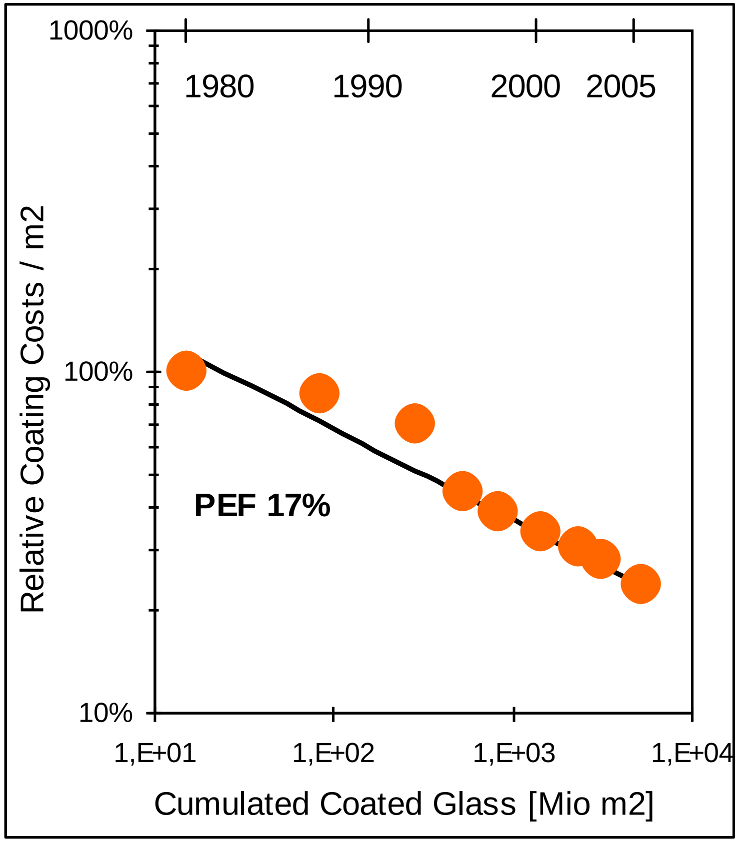
Leading Edge Values

Technology	PVD Sputtering
Glass Size:	3,21m x 6,0m
Layer Uniformity:	< 2%
Manuf. Line length:	200 - 250m
Vacuum pressure:	10^{-6} mbar
Output / min:	1,3 glasses
Output / year:	$10km^2$ (size of 1400 soccer fields)

Ref.: Applied Materials, glass division, 2009

Glass Coating

Price Experience Curve



Source: Applied Materials, Energy and Environmental Solutions, 2009

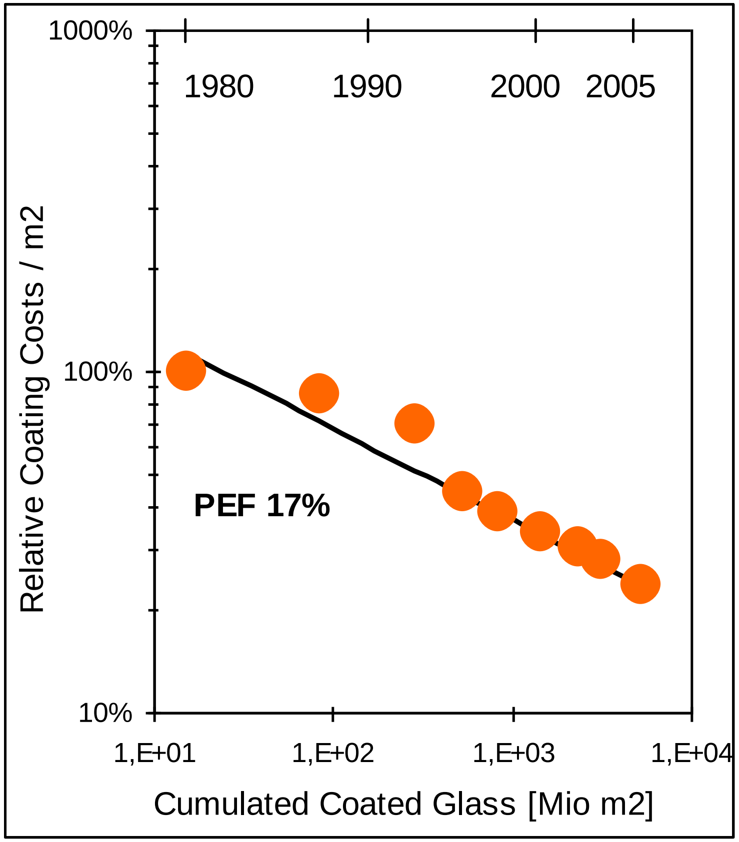
Glass Coating Equipment

Technology	PVD Sputtering
Glass Size:	3,21m x 6,0m
Layer Uniformity:	< 2% for layers in the 5-20nm range
Manuf. Line length:	200m - 250m
Output / year:	10km2 (size of 1400 soccer fields) corresponding to 2GW (at 20% efficiency)

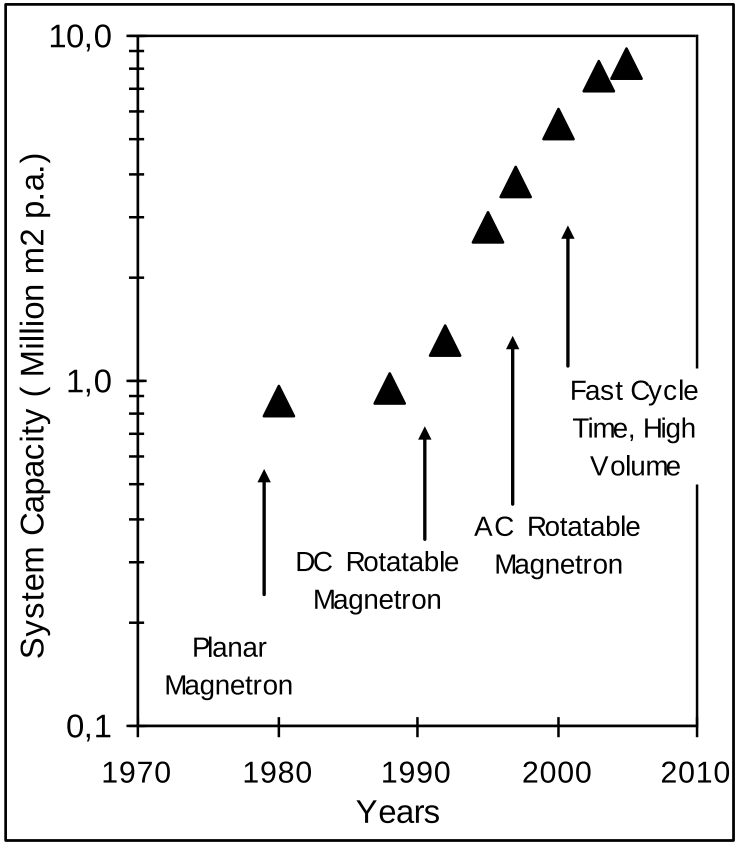
Source: Applied Materials, Energy and Environmental Solutions, 2009

Glass Coating

Price Experience Curve

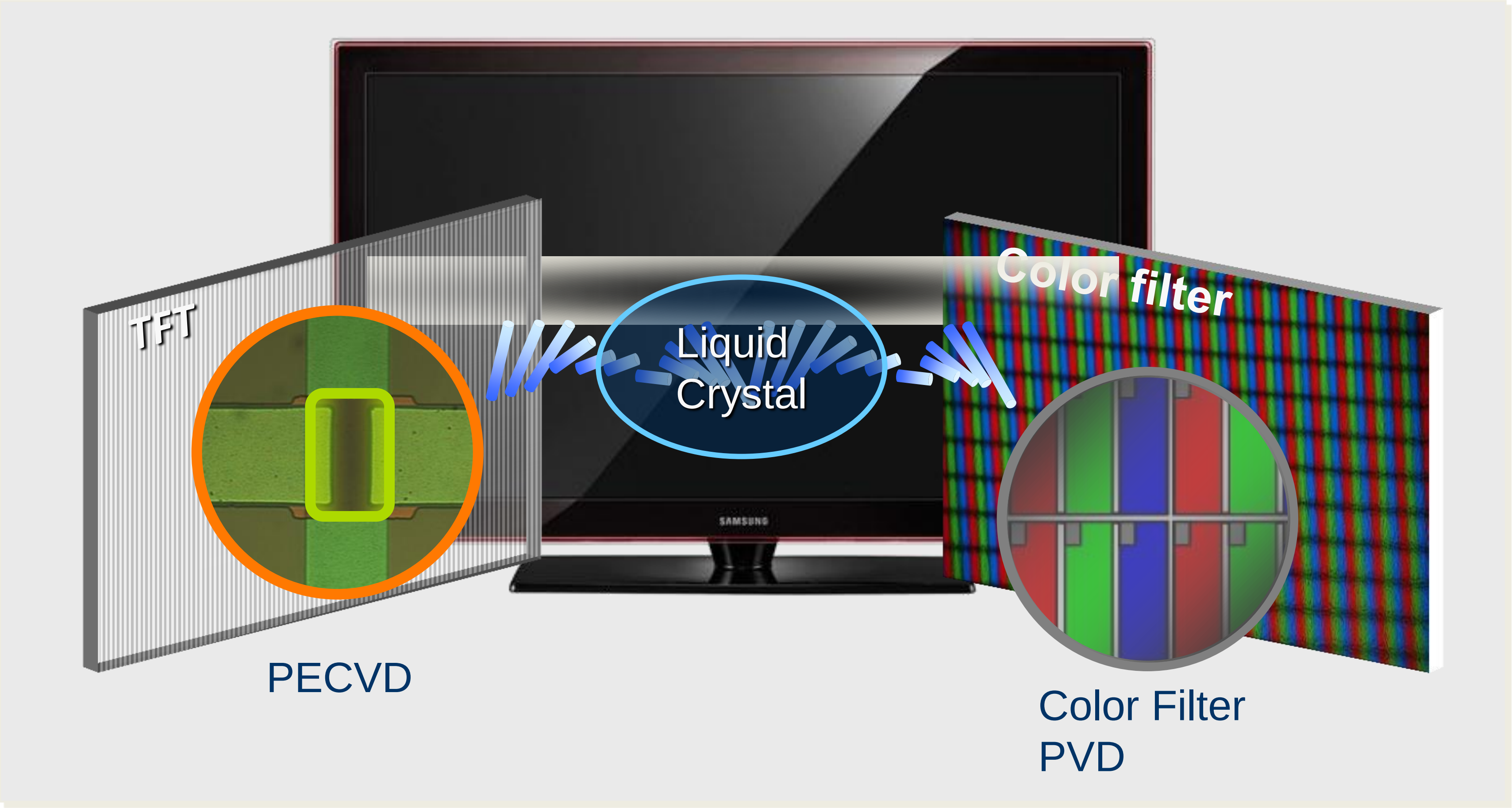


Driven by Technology



Source: Applied Materials, Energy and Environmental Solutions, 2009

Display: TFT-LCD Panel Technology

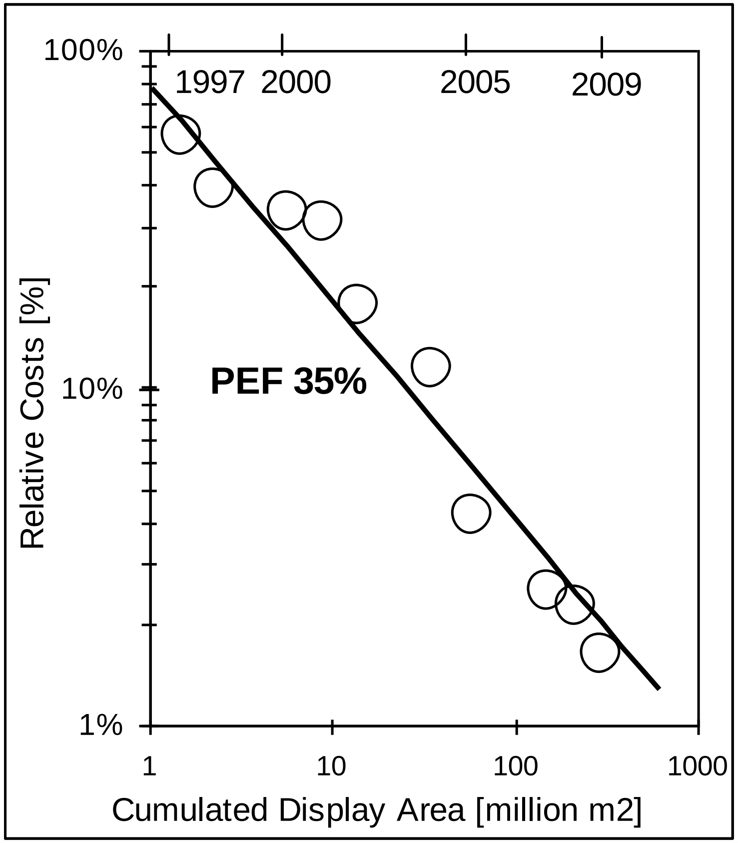


PECVD

Color Filter
PVD

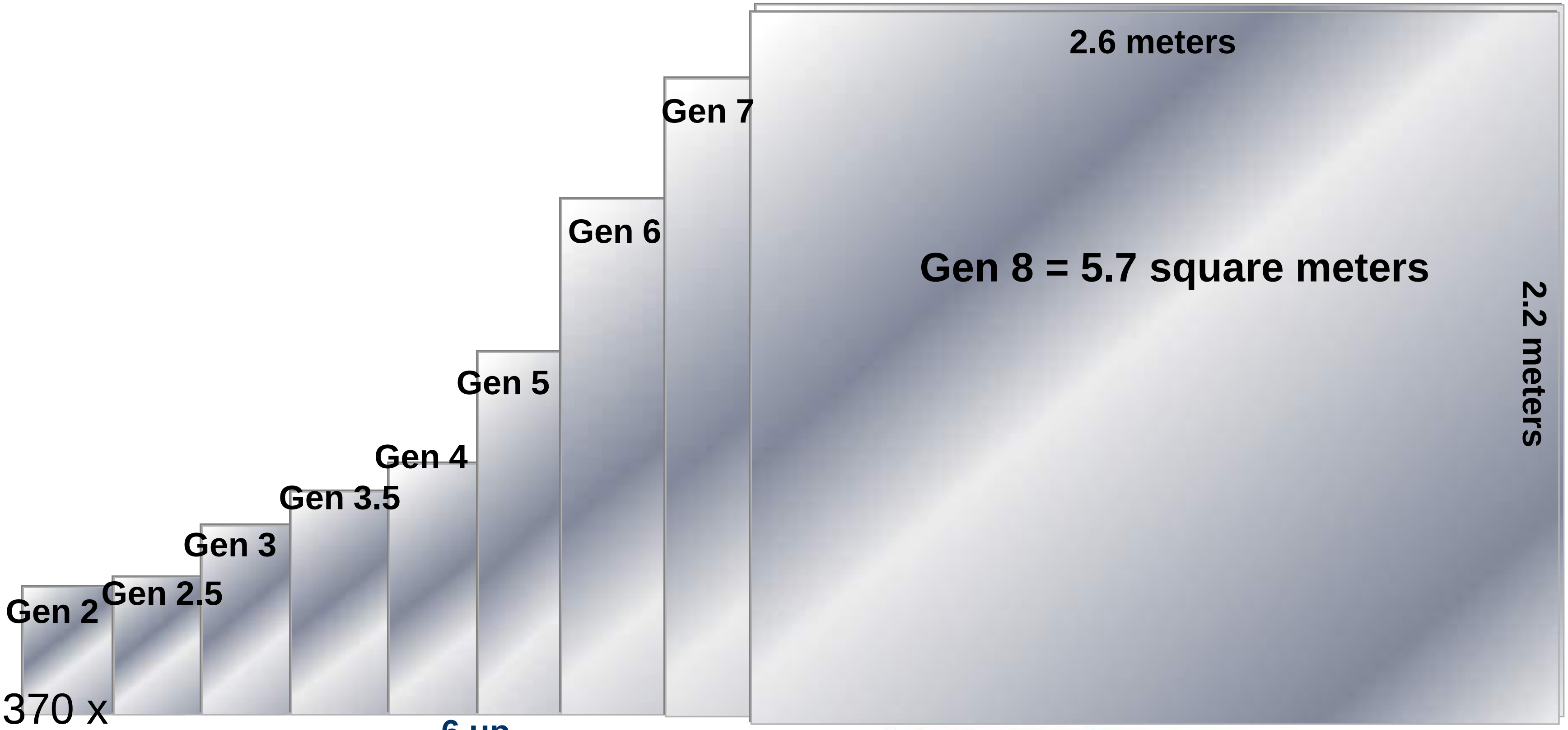
Display – Experience Curve

Experience Curve



Source: Applied Materials, Display Group, 2009

Substrate Size Expansion in LCD



2.6 meters

2.2 meters

Gen 8 = 5.7 square meters

Gen 7

Gen 6

Gen 5

Gen 4

Gen 3.5

Gen 3

Gen 2.5

Gen 2

370 x 470mm

4 up 10.4”

6 up 12.1”

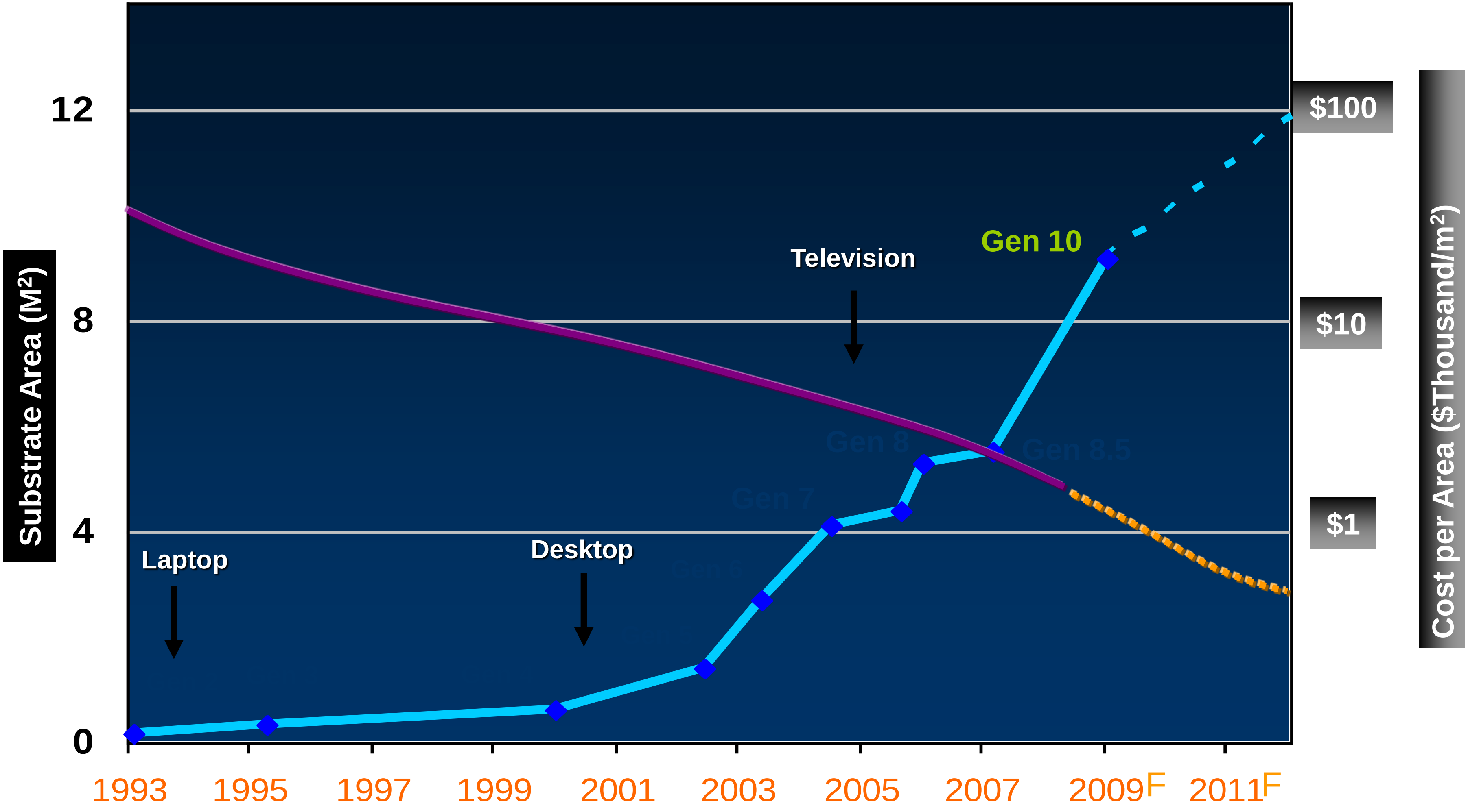
6 up 15 ~ 17

6 up 19 ~ 24”

6 up x 37” wide

6 up x 52” wide

Glass Size Increase in the Display Industry– Driving Cost Reduction



Source: Display Search, Applied Materials, 2009

TFT-LCD Panel Technology

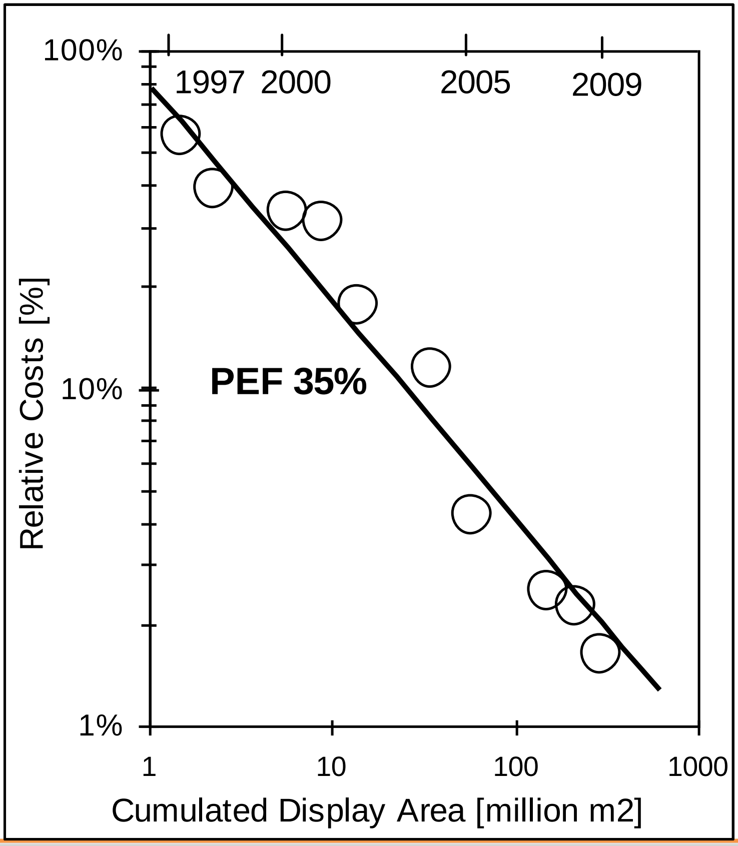
TFT PECVD

Color Filter PVD

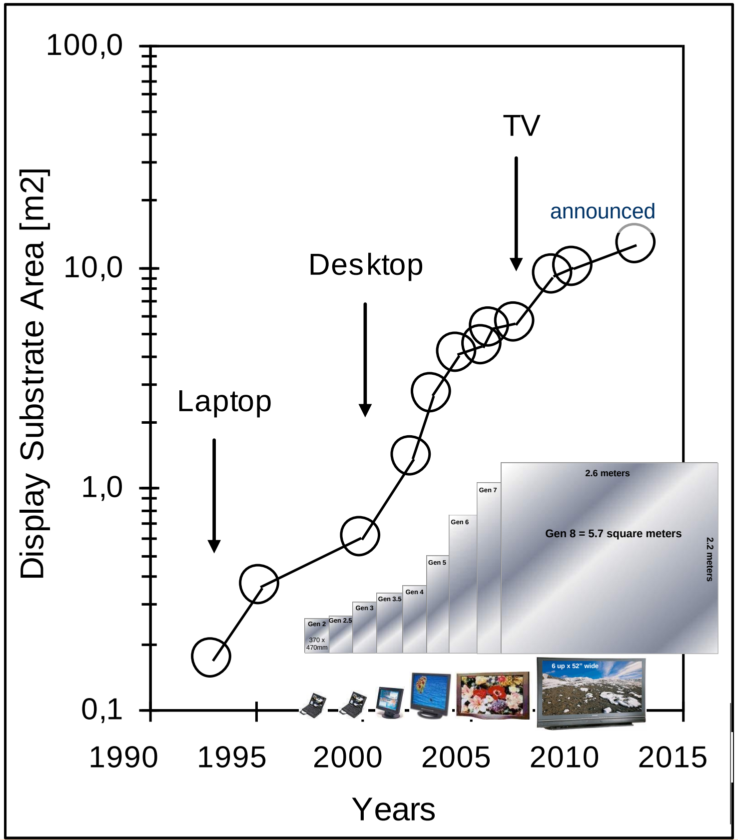
Source: Applied Materials, Display Group, 2009

Display

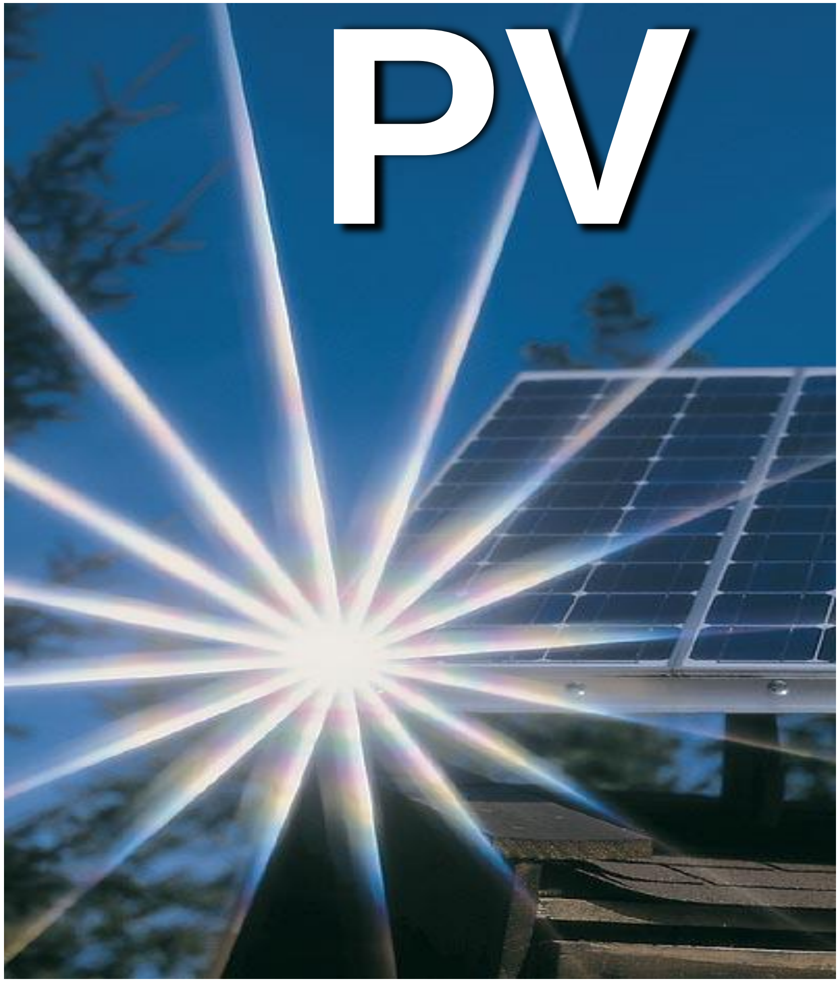
Experience Curve



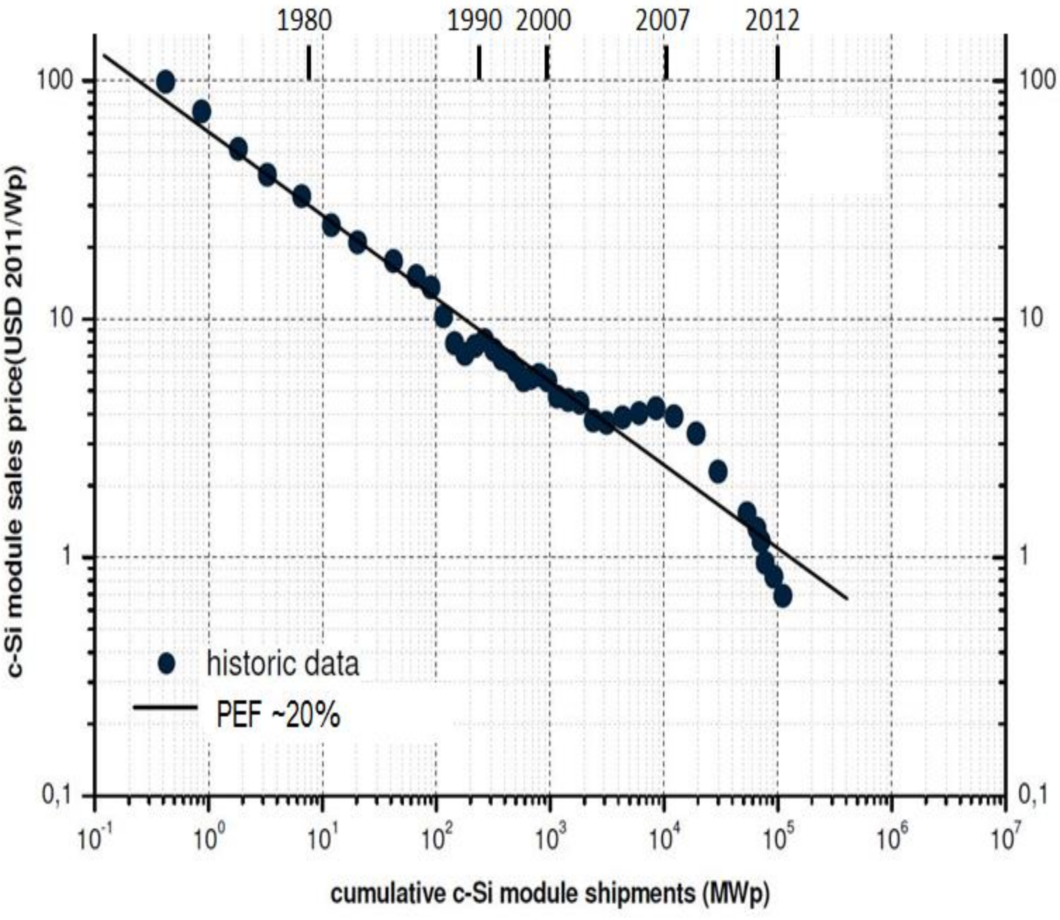
Driven by Technology



Source: Applied Materials, Display Group, 2009


PV

Price Experience Curve for PV



Source: ITRPV 2013

Specific material cost: example silicon:

~1975 → 2015

- Wafer thickness 700 → 150µm
- Kerf loss 500 → 100µm

  → weight 28 → 6 g/dm(2)
- Poly Si 60 → 15 $/kg

  → material cost 1.68→ 0.09 $/dm(2)
- Efficiency 8 → 20%

  →**spec. Cost** 2,10 → 0.045 $/W

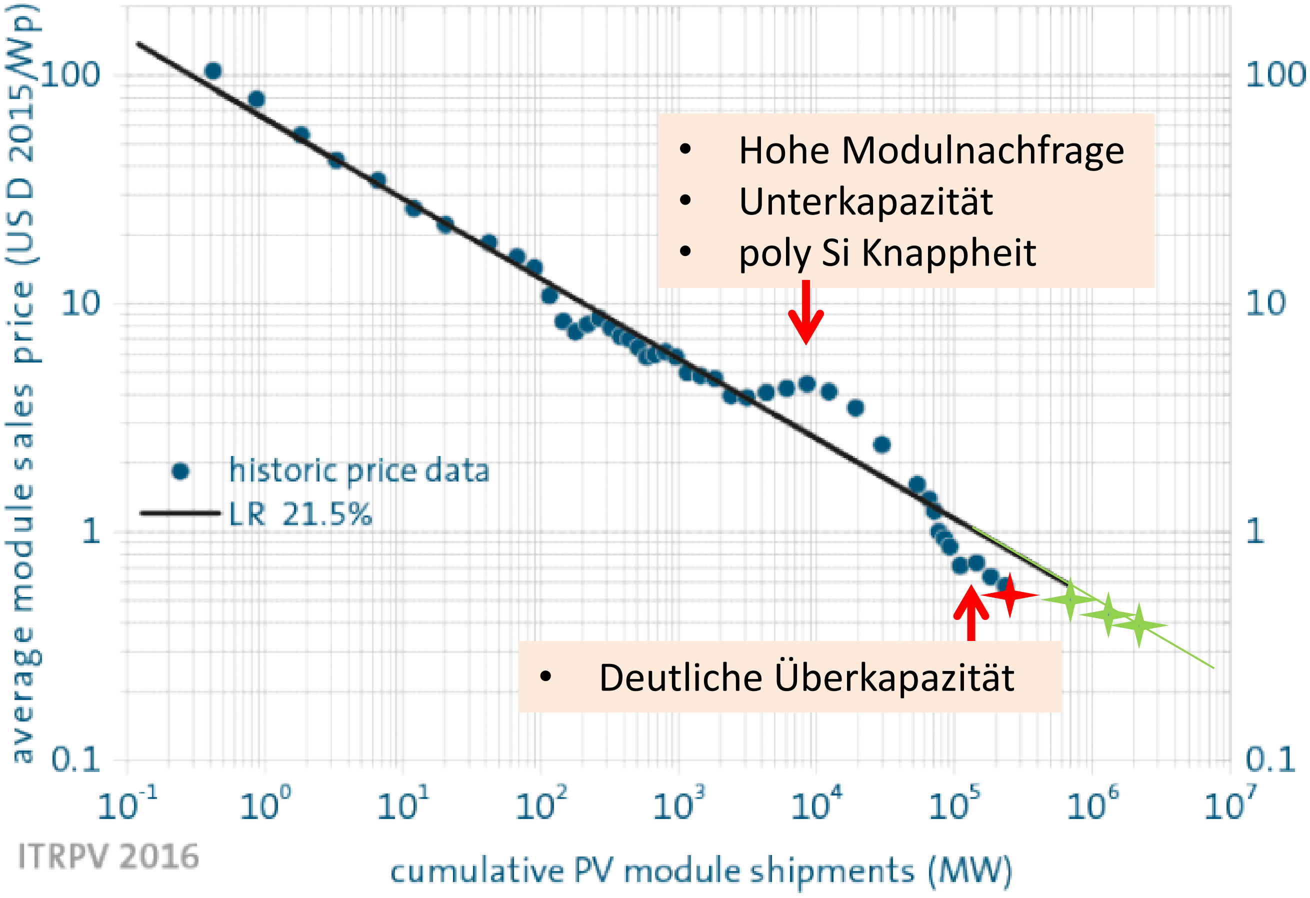
  reduction by factor ~50!

Economy of scale & industrial manufacturing

- **Production line 24/7**

  1 MW → 200 MW
- **Automation & high yield**
- **Production processes with low specific cost for high volume**

Preis-Erfahrungs-Kurve für PV Module



- Hohe Modulnachfrage
- Unterkapazität
- poly Si Knappheit

- Deutliche Überkapazität

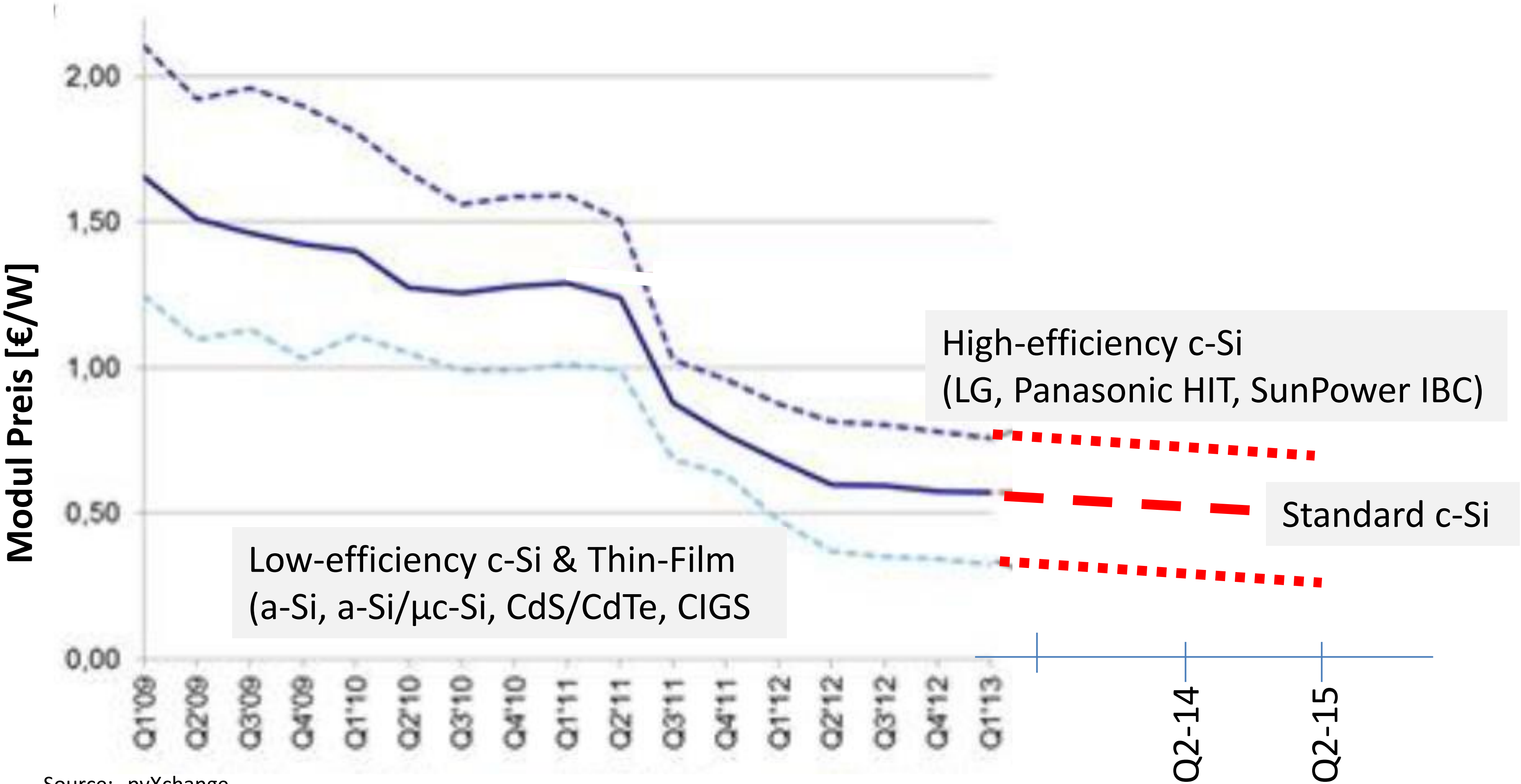
Source: ITRPV 2016, beyond 230 GW cum volume Winfried Hoffmann (green stars and line)

LR 21,5% bedeutet:

@ Verdoppelung der ***kumulierten*** Menge →

Preisreduktion um 21,5%

Entwicklung der Verteilung von PV - Modulpreisen



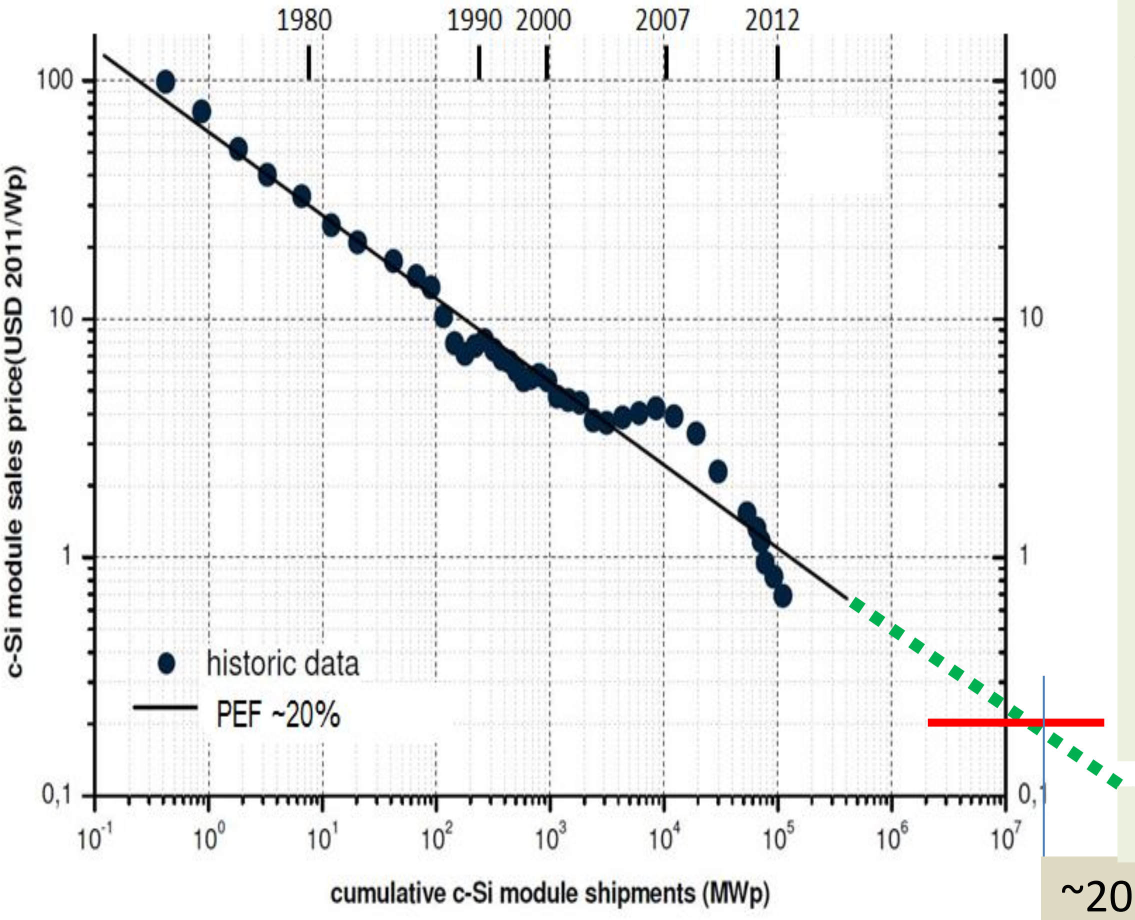
High-efficiency c-Si
(LG, Panasonic HIT, SunPower IBC)

Standard c-Si

Low-efficiency c-Si & Thin-Film
(a-Si, a-Si/µc-Si, CdS/CdTe, CIGS

Source: pvXchange

Extrapolation for PV
Price Experience Curve



~20 TW

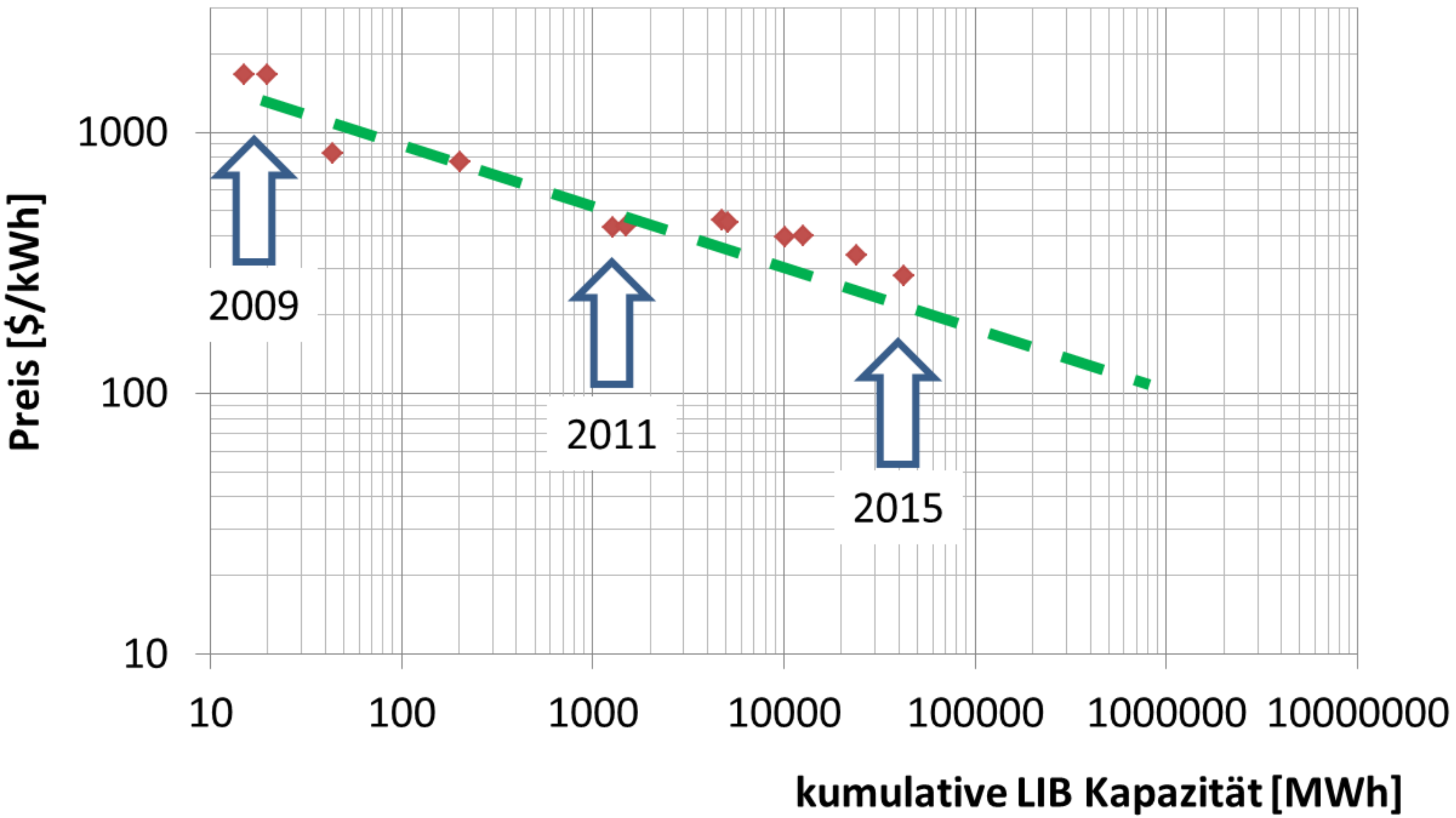
Source: ITRPV 2013

„Grenzkosten c-Si Module“

- **Wafer**
  200x200mm², 80/70µm,
  12$/kg, eta 25% $ct/W 2
  andere Mat. $ct/W 2
- **Zelle** $ct/W 2
- **Modul**
  Do-Glas a 1,4 mm $ct/W 4
  Verschalt&Verkaps $ct/W 3
  Kabel, b-rail etc $ct/W 3
- **OPEX (~80%) $ct/W 16**
- **Rest (~20%) $ct/W 4**

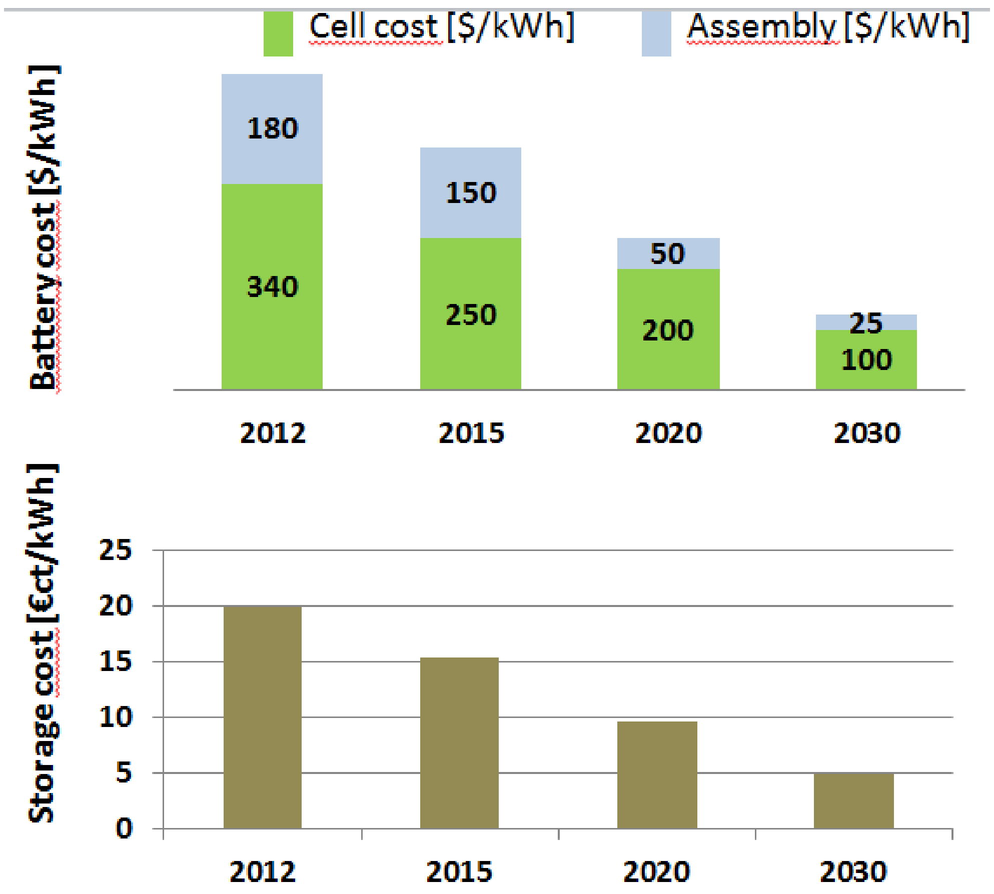
- **Gesamt $ct/W 20**

Continuation of PEC for LIB batteries for automotive applications



Source: raw data from personal communication C. Pillot, Avicenne

LIB cell- and battery cost and resulting storage cost



Simplified calculation for the cost of a stored kWh by a LIB battery:

- Lifetime 5,000 cycles
- Financing cost ~ same as investment
- Usable capacity per cycle ~80%

Cost per kWh = (I x 2)/(5,000 x 0.8)

Source: LIB cost 2012, 2015 and 2020 from C. Pillot (2014), avicenne; 2030/35 LIB cost, storage cost and conclusions are own estimates

Die Integration erneuerbarer und variabler Stromerzeuger (PV & Wind) In die künftige Energiewelt

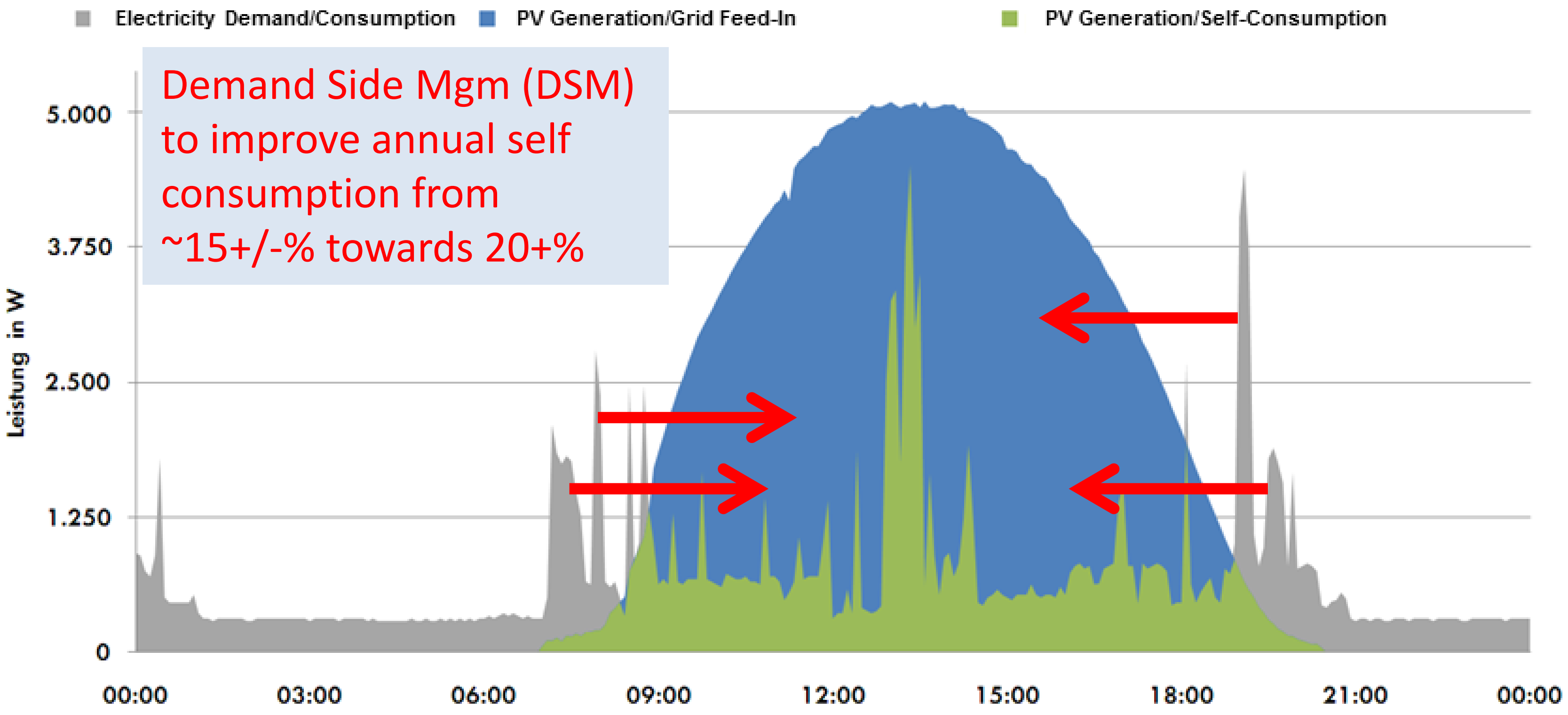
Source:

Smart Home

Smart Homes with *PV [~kW]
*battery [~kWh]
*Smart meter/home manager
*Demand Side Mgm
*Dual house wiring (DC & AC)
*e-car
*B2B electricity trading
[*of course well insulated/ventilated]

Source: 170501_Winfried Hoffmann_ASE

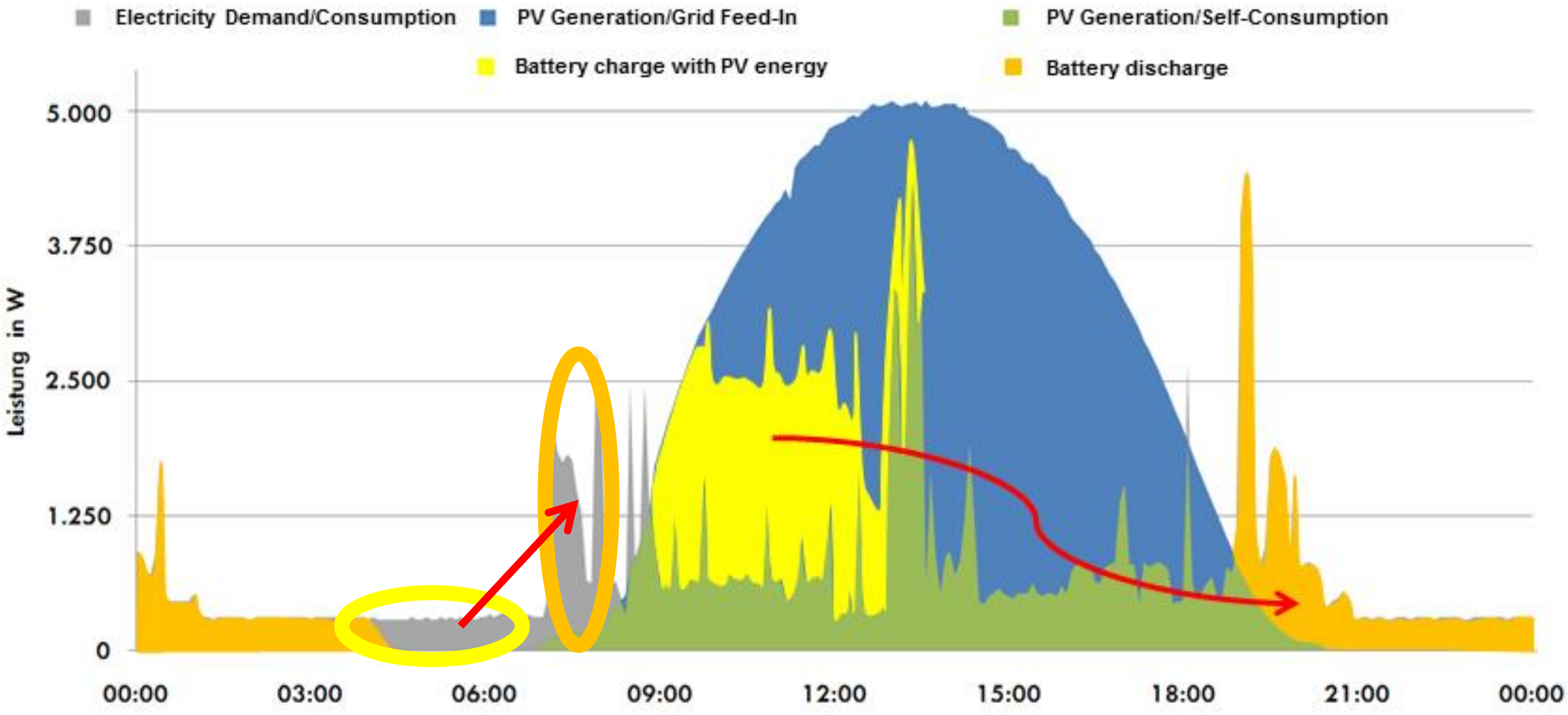
Load curve for a German home and PV – electricity generation profile



Demand Side Mgm (DSM) to improve annual self consumption from ~15+/-% towards 20+%

Source: SMA Solar Technology AG (2011)

Load curve for a German home and PV –profile with battery storage



Source: SMA Solar Technology AG (2011)

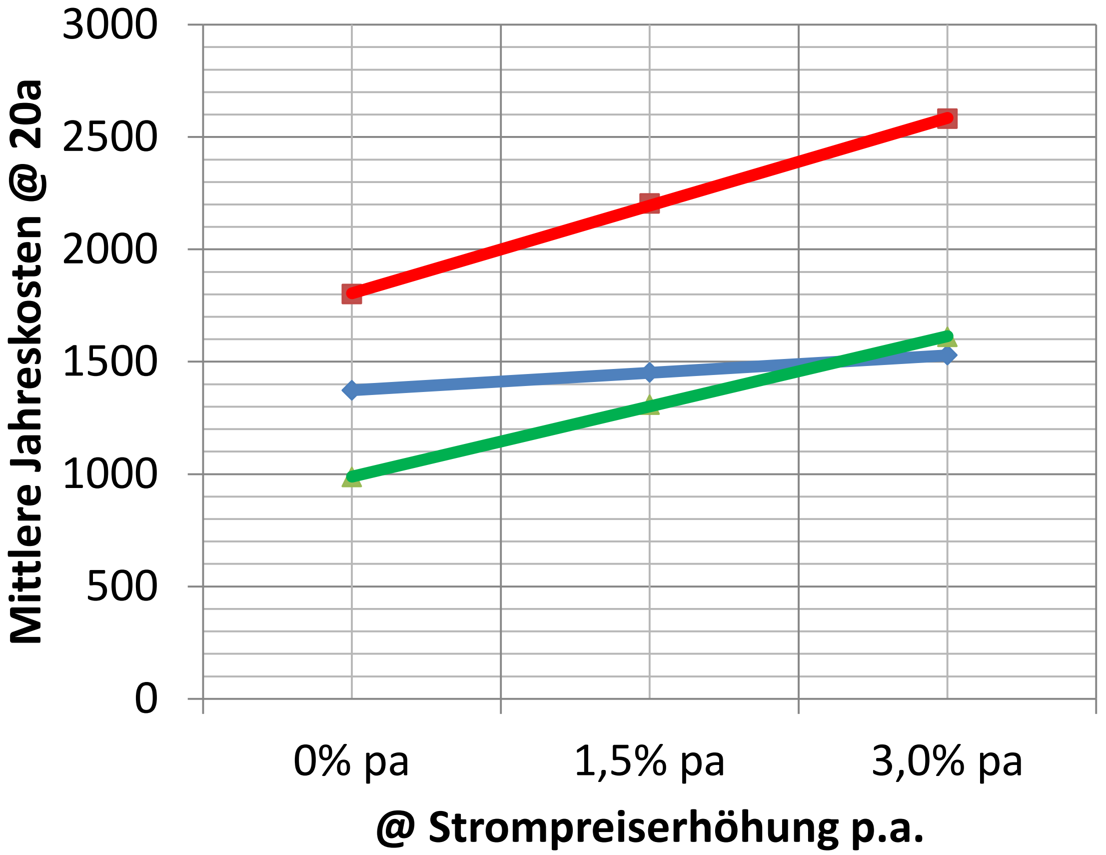
Privathaus mit ~4,500 kWh (+1,500 kWh for e-car) Stromverbrauch p.a.

- *Haus mit 6 kW PV System*
- Eigenverbrauch p.a.
  <~ 20% = 1,200 kWh
  x 0.13 €/kWh = 156 €
- Verkauf ins Netz 4,800 kWh x 0.127 €/kWh = +610 € (EEG)
- @30€ct/kWh vom EVU
  →4,800kWh x 0.3 €/kWh
  = 1,440 €
- *Total 986 €*

- *Smart home mit 6 kW PV und Batteriespeicher*
- Eigenverbrauch p.a.
  ~80% = 4,800 kWh
  x 0.13 €/kWh = 624 €
  + 3,600 kWh x 0.15 €/kWh = 540 € Speicherkosten
- Ins Netz: 1,200x0.127 = +152 €
- Vom EVU
  1,200 kWh x 0.3 €/kWh
  = 360 €
- *Total 1,372 €*

Source: Winfried Hoffmann (11/2016)

Jahreskosten für 6.000 kWh Haushalt (a) nur EVU, (b) +PV und (c) +PV+Batt



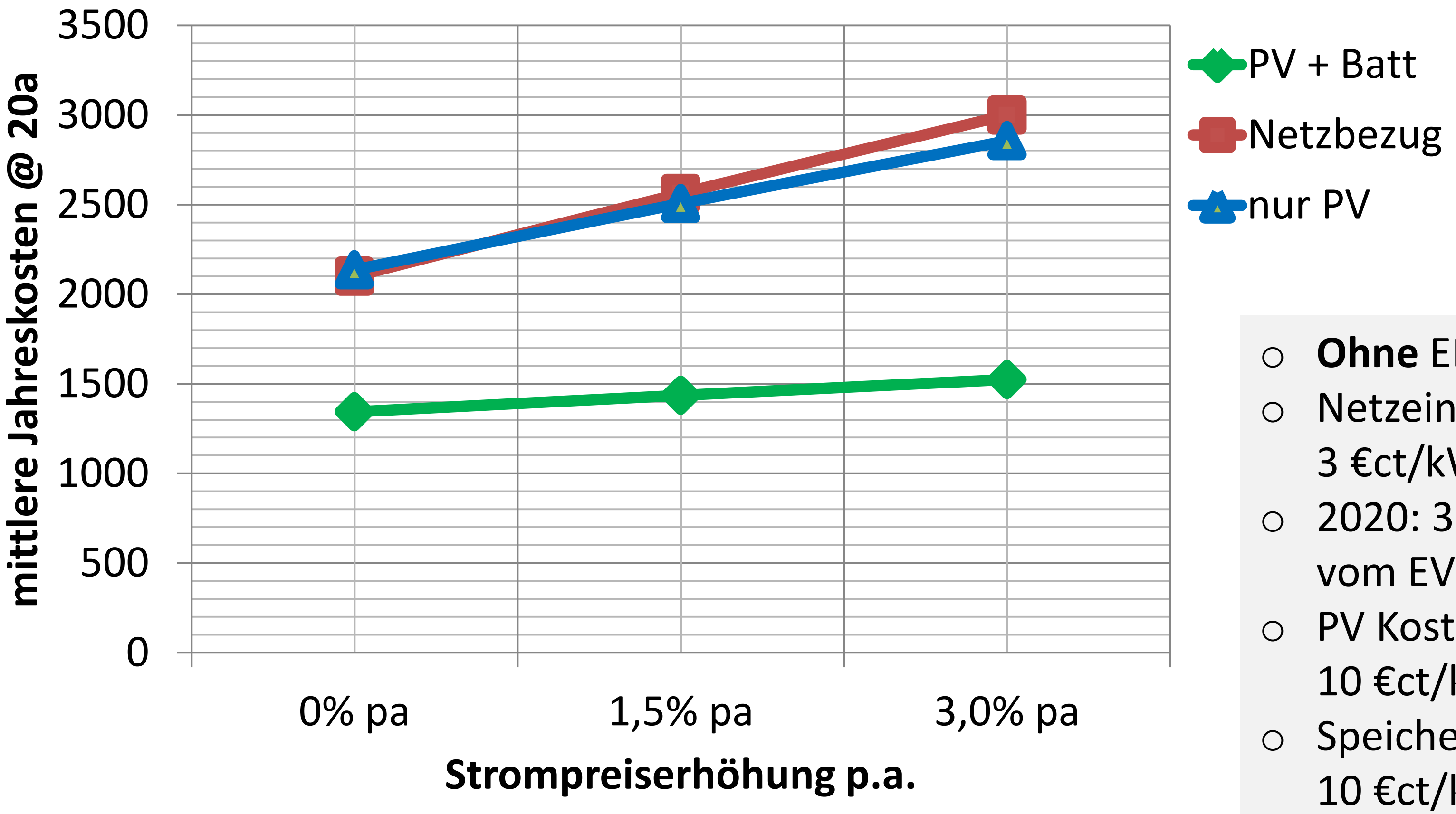
2015

- ○ **mit** EEG (2016)
- ○ Netzeinspeisung 3 €ct/kWh
- ○ 2015: 30 €ct/kWh vom EVU
- ○ PV Kosten 13 €ct/kWh
- ○ Speicherkosten 15 €ct/kWh

Source: Winfried Hoffmann (11/2016)

Jahreskosten für 6.000 kWh Haushalt (a) nur EVU, (b) +PV und (c) +PV+Batt

2020



- ○ **Ohne** EEG
- ○ Netzeinspeisung 3 €ct/kWh
- ○ 2020: 35 €ct/kWh vom EVU
- ○ PV Kosten 10 €ct/kWh
- ○ Speicherkosten 10 €ct/kWh

Source: Winfried Hoffmann (11/2016)

New battery technologies for stationary use

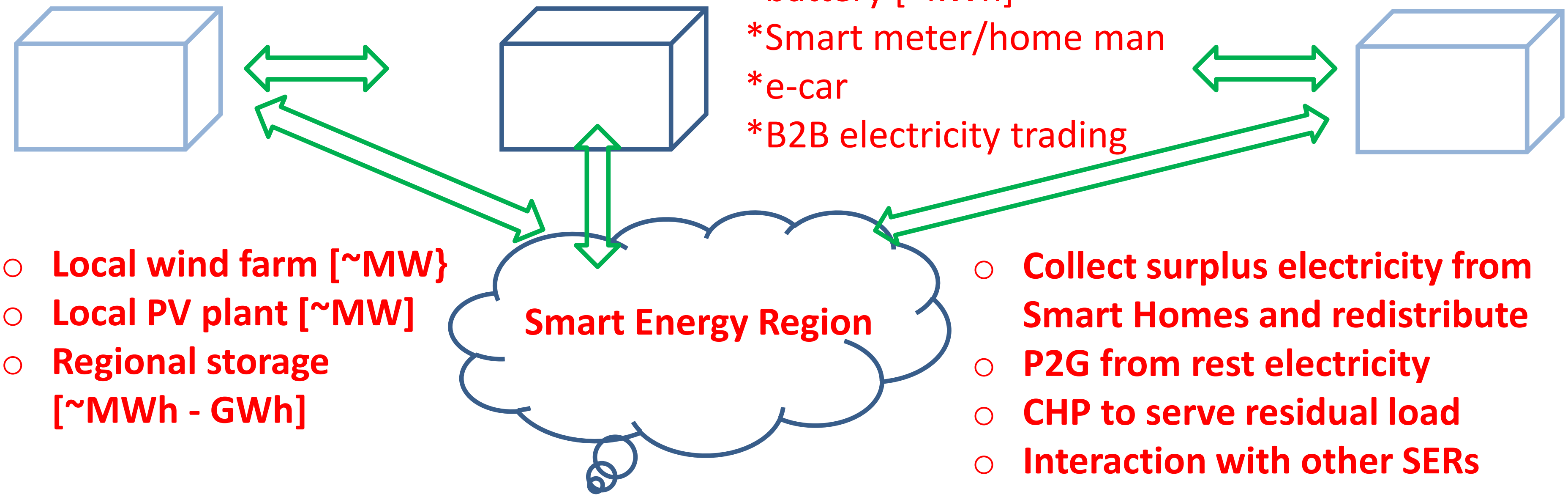
The battery industry is forced by the **automotive industry** to quickly provide **cheap (€/kWh) AND light weight batteries** (kg/kWh). With today‘s materials this is only achieved with **Li based batteries**.

Electricity storage for **stationary use** (e.g. in houses) has just started. This application has **no restrictions** regarding **weight and volume per kWh**. Most probably there will be cheaper battery technologies (€/kWh) in the future. However, the battery industry is reluctant to invest in additional technologies.

Regardless which battery technologies – redox flow, non Li type batteries like NaS, etc - will enter the market place in the future: the PEC for LIB tells us that the price for those **new types** will have to be at least **the same, better less expensive**, compared to LIB – and this with much less production volume in the beginning!

Source: Winfried Hoffmann _ ASE (6/2017)

Overview
Smart Home / Smart Energy Region



Smart Homes with *PV [~kW]
*battery [~kWh]
*Smart meter/home man
*e-car
*B2B electricity trading

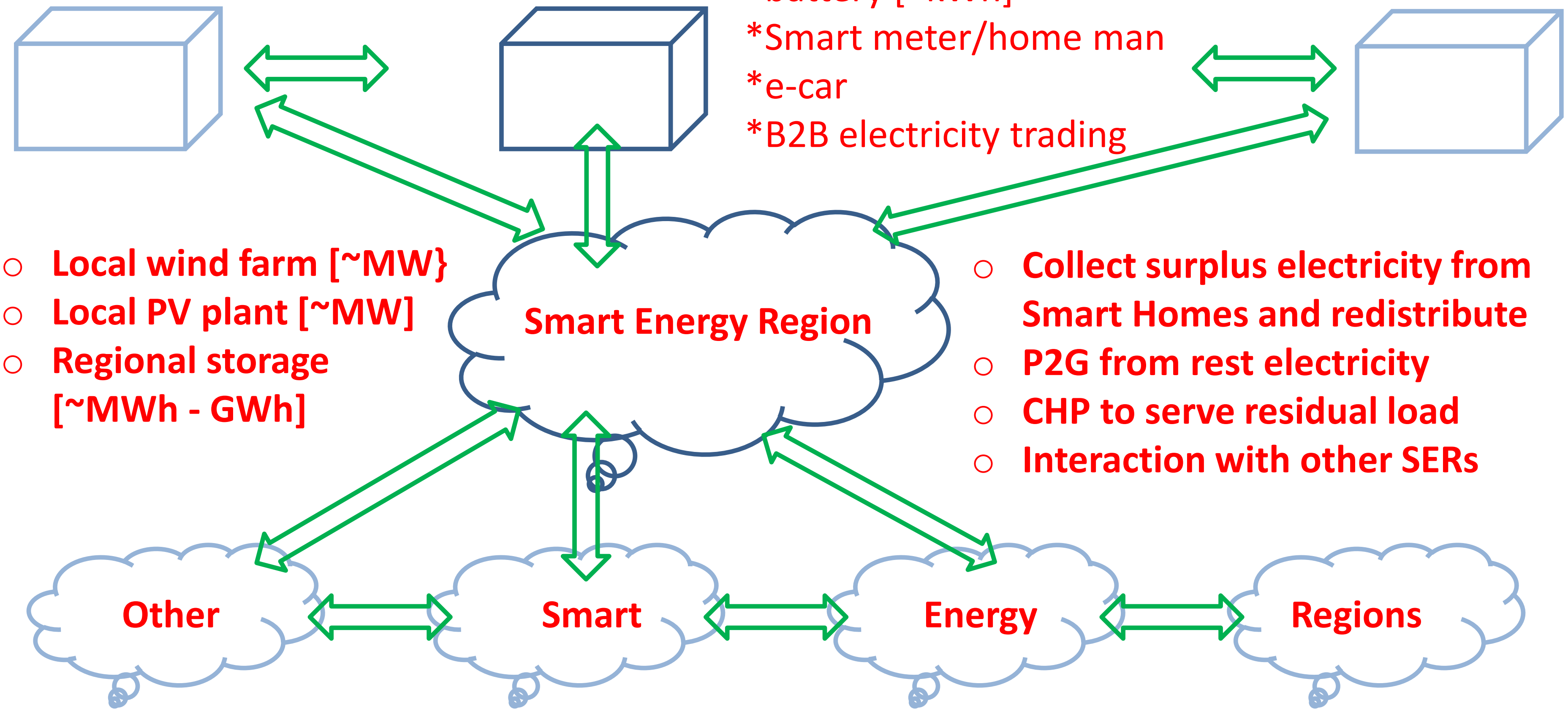
- ○ **Local wind farm [~MW}**
- ○ **Local PV plant [~MW]**
- ○ **Regional storage [~MWh - GWh]**

Smart Energy Region

- ○ **Collect surplus electricity from Smart Homes and redistribute**
- ○ **P2G from rest electricity**
- ○ **CHP to serve residual load**
- ○ **Interaction with other SERs**

Source:

Overview
Smart Home / Smart Energy Region



Smart Homes with *PV [~kW]
*battery [~kWh]
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- ○ **Local wind farm [~MW}**
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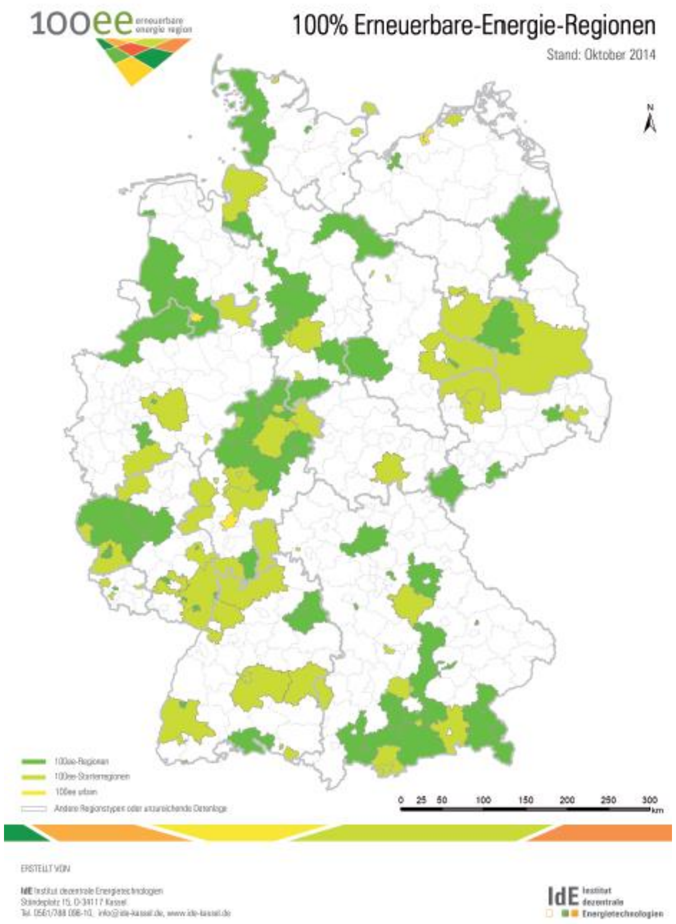
- ○ **P2G from rest electricity**
- ○ **CHP to serve residual load**
- ○ **Interaction with other SERs**

Source: 170501_Winfried Hoffmann_ASE

Existing „smart energy regions“ in Germany as of 2016

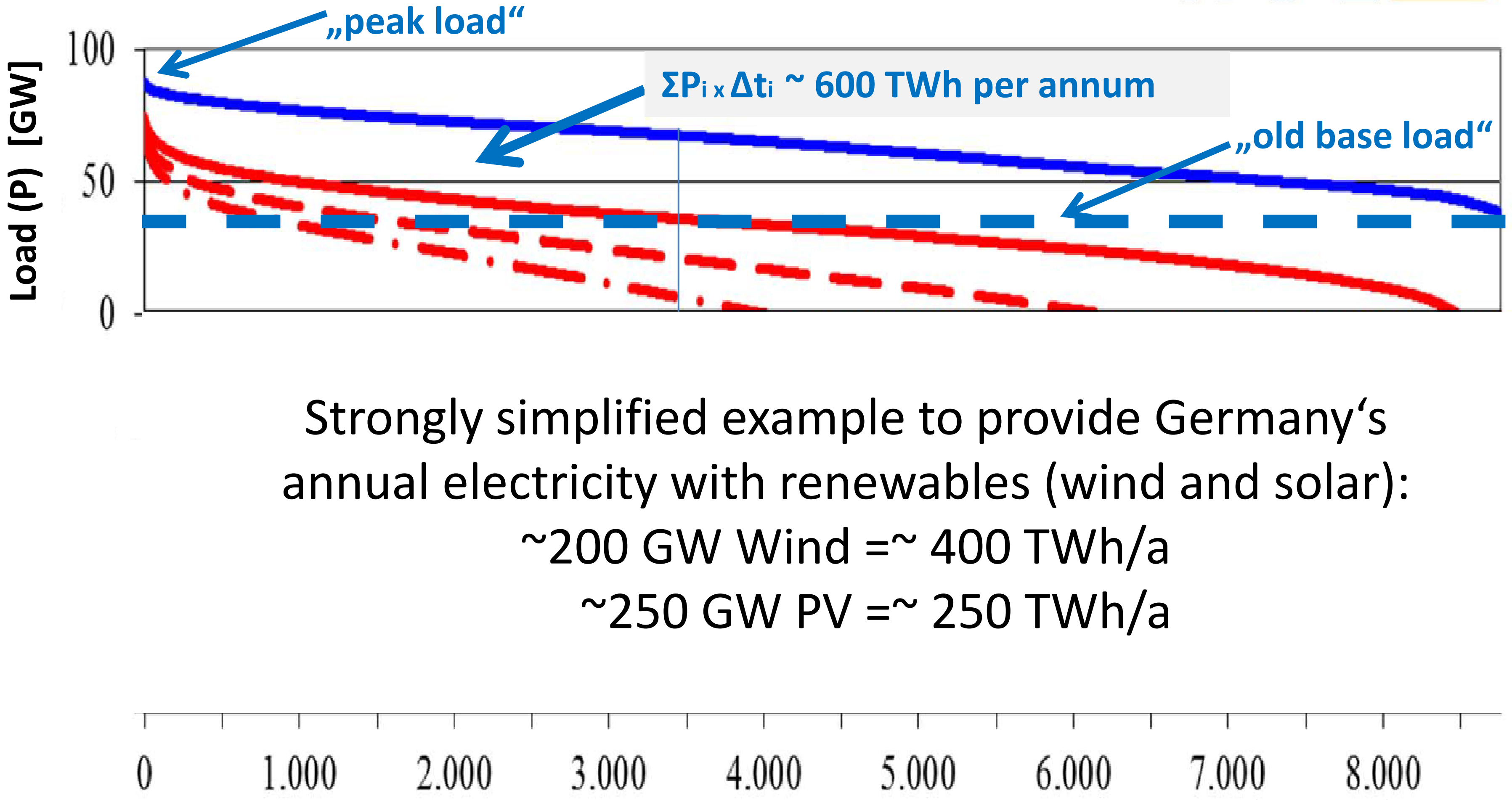


Source: IdE Kassel

146 regions
~25 million people

The shown local regions have politically decided to have within a defined time scale (10 – 20 years) **their energy provided by ~100% Renewables**. Beside a locally optimized portfolio (wind, solar, thermal, bioenergy etc.) it is a **prerequisite to have storage available** for not only serving the annual energy but also the needed actual power.

Electricity load curve for Germany

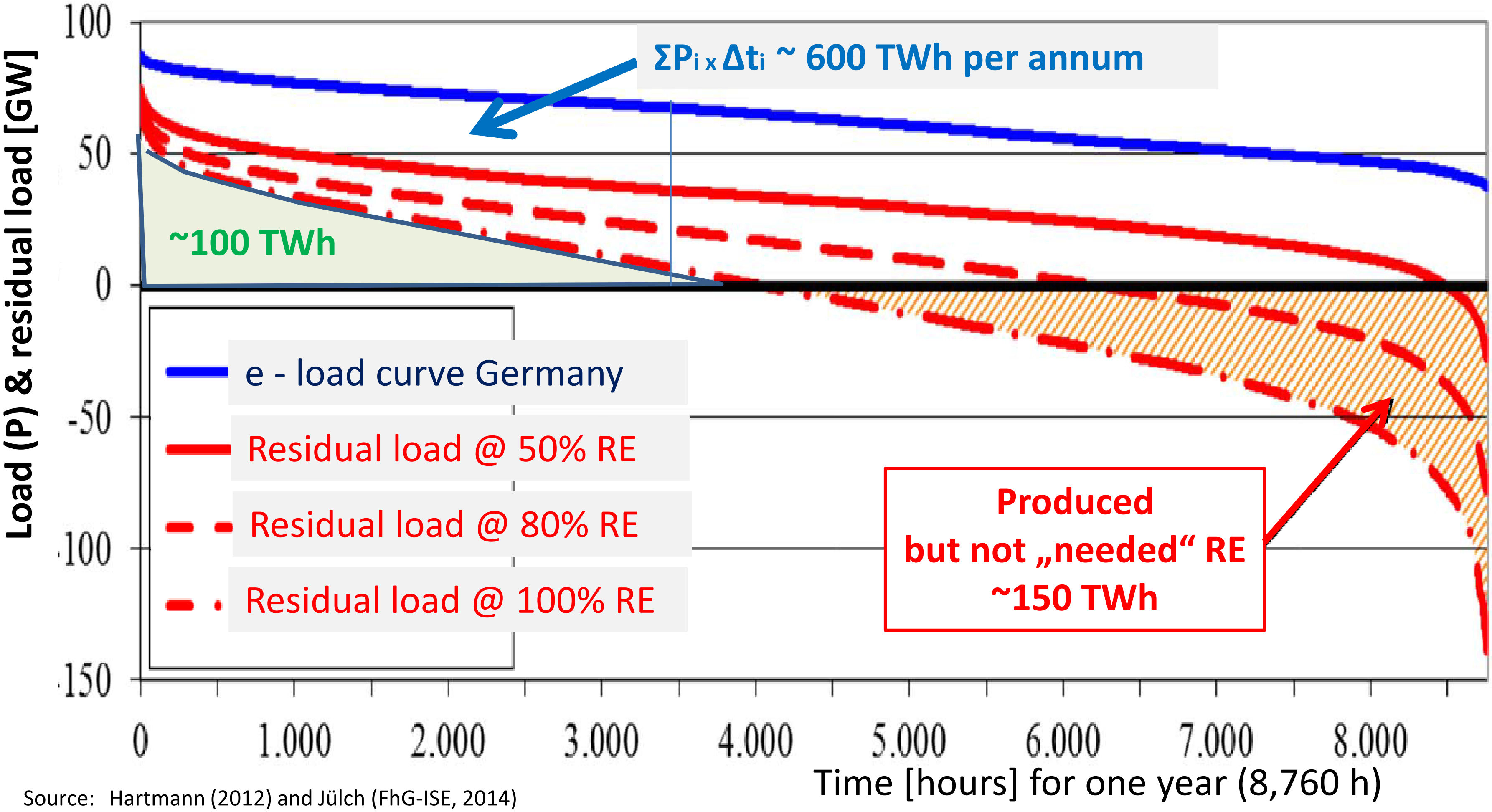


Strongly simplified example to provide Germany‘s annual electricity with renewables (wind and solar):
~200 GW Wind =~ 400 TWh/a
~250 GW PV =~ 250 TWh/a

Time [hours] for one year (8,760 h)

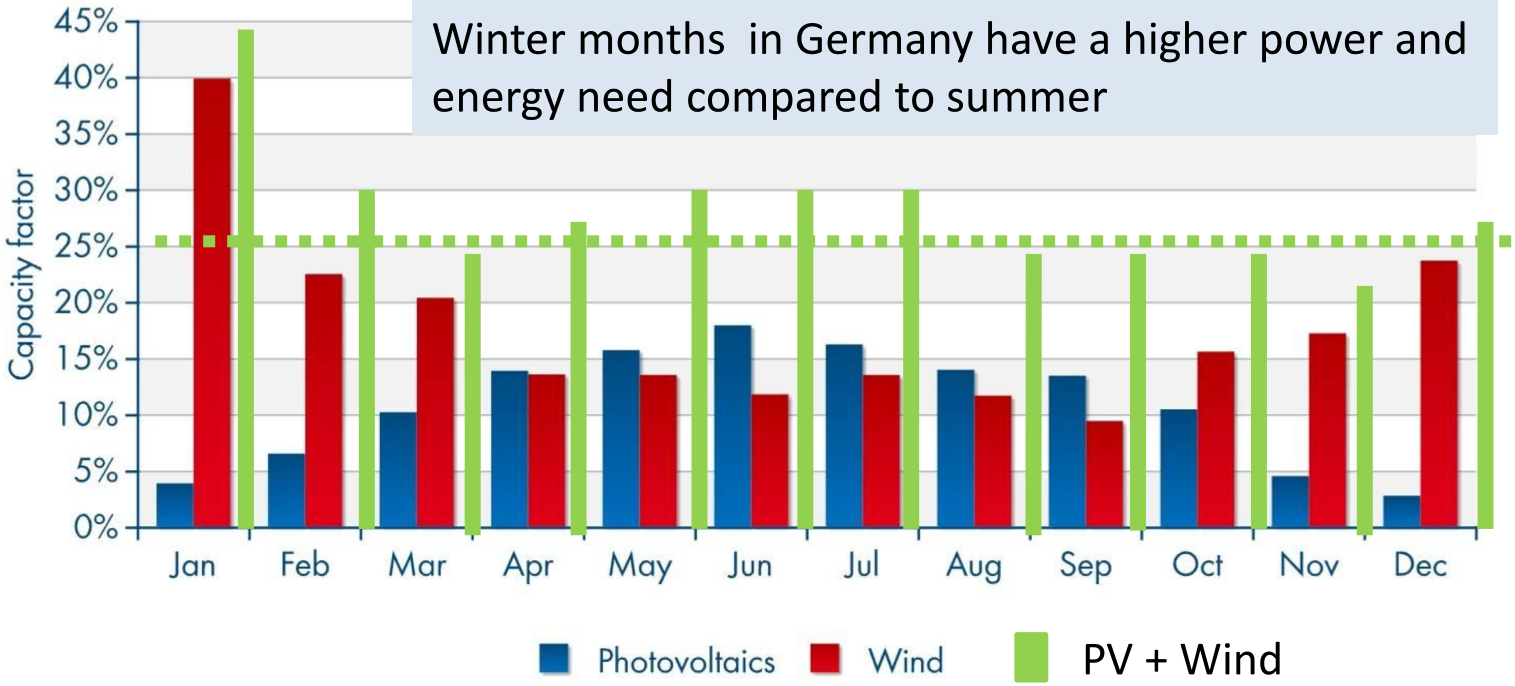
Source: Hartmann (2012) and Jülch (FhG-ISE, 2014)

Germany‘s load curve and residual load with Renewable Energy (RE)



Source: Hartmann (2012) and Jülch (FhG-ISE, 2014)

Average monthly grid feed-in of PV- and wind-power in Germany



Winter months in Germany have a higher power and energy need compared to summer

- Equal power of wind and solar leverage well the four seasons in Germany
- In northern Europe more wind
- In southern regions more PV (power and energy peak shifted to summer)

Source: SMA Solar Technology AG (Engek)

ppa for new PV in Germany and Dubai

PV green field in Germany (1) **~1,0 kWh/W$_{PV}$**

- Average bid <5 €ct/kWh for a ~100 MW system (lowest 4.29 €ct/kWh)
- Duration 20 years with no inflation adjustment
- Expected completion ~1 year after start of work
- With module warranties of 25 up to 30 years it is conservatively expected that the PV plant will work at least for another 10 years with a maintenance and repair cost of ~1 €ct/kWh)

PV green field in Dubai (2) **~1,8 kWh/W$_{PV}$**

- Lowest bid 2.99 $ct/kWh (=~ 2.7 €ct/kWh) **(investment <1€/W)**
- Duration 20 years with no inflation adjustment
- Expected completion ~1 year after start of work
- Same assumptions for additional 10 years as in (6,9/1,8 = 3,8)

PV green field Chile (3) **~2,3 kWh/W$_{PV}$**

- Lowest bid by Solarpack at 2,91 $ct/kWh (=~ 2.6 €ct/kWh) Duration 20 years with no inflation adjustment (6,9/2,3 = 3,0)

ppa for new nuclear

New nuclear „Hinkley point C1 and C2

- Two Areva EPR 1600 MW reactors, planned investment 26.5 bn **€** **(8.3 €/W)**
- EdF would only build these reactors if GB would accept a guaranteed price with the following conditions:
- 92.5 £/MWh (=~ 12 €ct/kWh)
- Duration 35 years after start of operation
- Adjustment according to inflation, starting with the basis year 2012
- Expected completion 9.5 years after start of work

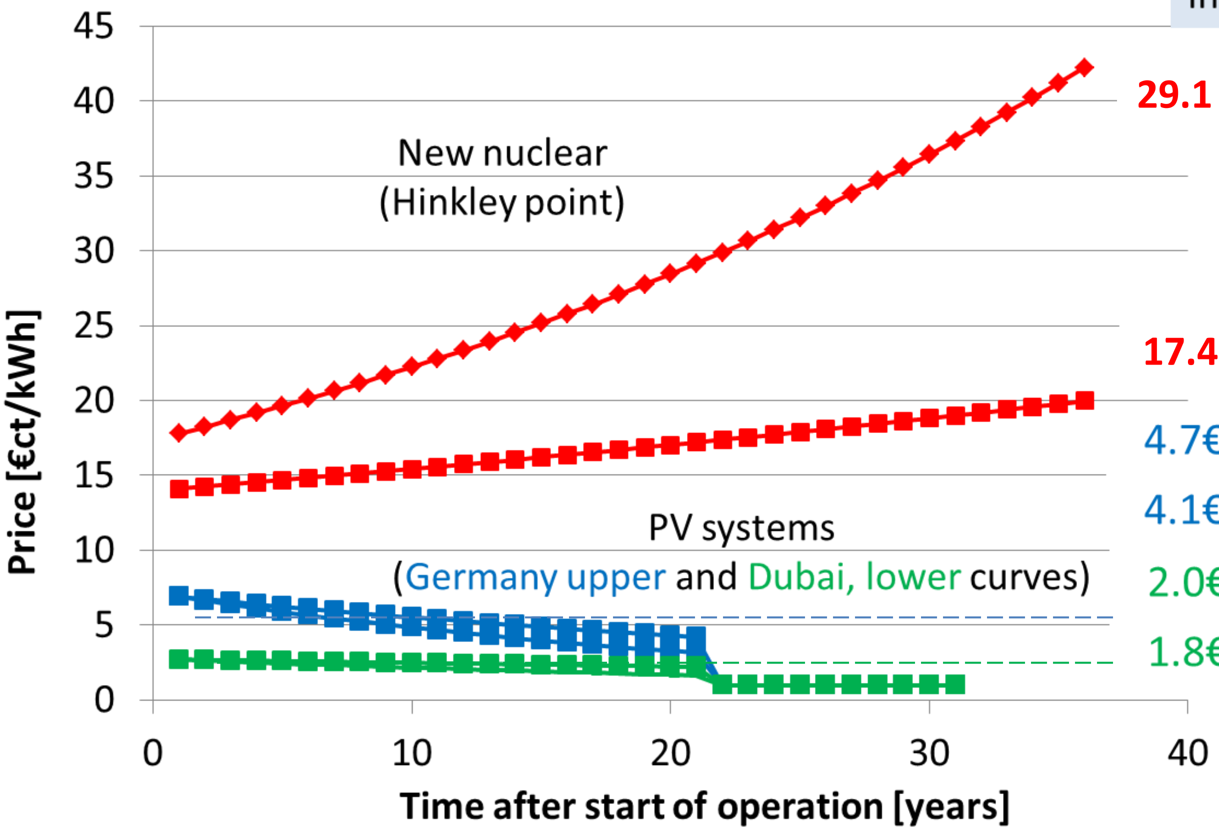
New Nuclear Power Stations in Hungary

- For comparison: as described in Handelsblatt 26.11.2015 there are two nuclear power stations (1200 MW each) planned in Hungary and built by a Russian consortium at a planned investment of **5.2 €/W**)

Source: BBC News 21.10.2013, Daily Telegraph 21.10.2013

Preis für PV und neue KKW‘s einschließlich Inflation

Average €ct/kWh @
inflation rate p.a. [%]



„effective“ price

29.1 ct/kWh@2.5% p.a. **~30 €ct/kWh**

17.4 ct/kWh@1.0% p.a. **~17 €ct/kWh**

4.7€ct/kWh@1.0% p.a.

4.1€ct/kWh@2.5% p.a.

~4,3 €ct/kWh

2.0€ct/kWh@1.0% p.a.

1.8€ct/kWh@2.5% p.a.

~2.3 €ct/kWh

Source: Winfried Hoffmann, 2016

Saubere Kohle und Gas …

Variante 1: CSS (Carbon Sequestration and Storage)

- Falls es überhaupt funktioniert – Endlagerung für immer! – sind die Erfahrungen der europäischen Stromkonzerne sehr ernüchternd, nämlich viel zu teuer (>10 €ct/kWh)
- Die anfallenden Mengen sind im wahrsten Sinne des Wortes „erschlagend“!

Variante 2: CO_2 Steuer pro Tonne

Nach der Einführung des europäischen Emissionshandels war der CO_2 - Preis pro t in den Jahren 2005/06 zwischen 20 und 30 €/t, fiel 2007 auf <7 €/t und ist heute bei ~6 €/t. GB hat seit 2015 einen Preis von 30 €/t fest gelegt. Um die Klimaziele von Paris zu erreichen, werden Preise ab **2020 von ~50 €/t** und ab **2030 ~100 €/t** nötig!

Bei **50 €/t [100 €/t]** ergäben sich folgende Belastungen für:
Braunkohle @~1,2 kg CO_2 /kWh → 6 €ct/kWh [12 €ct/kWh]
Steinkohle @ ~0,9 - “ - → 4,5 €ct/kWh [9 €ct/kWh]
Gas @ ~0,4 - „ - → 2 €ct/kWh [4 €ct/kWh]

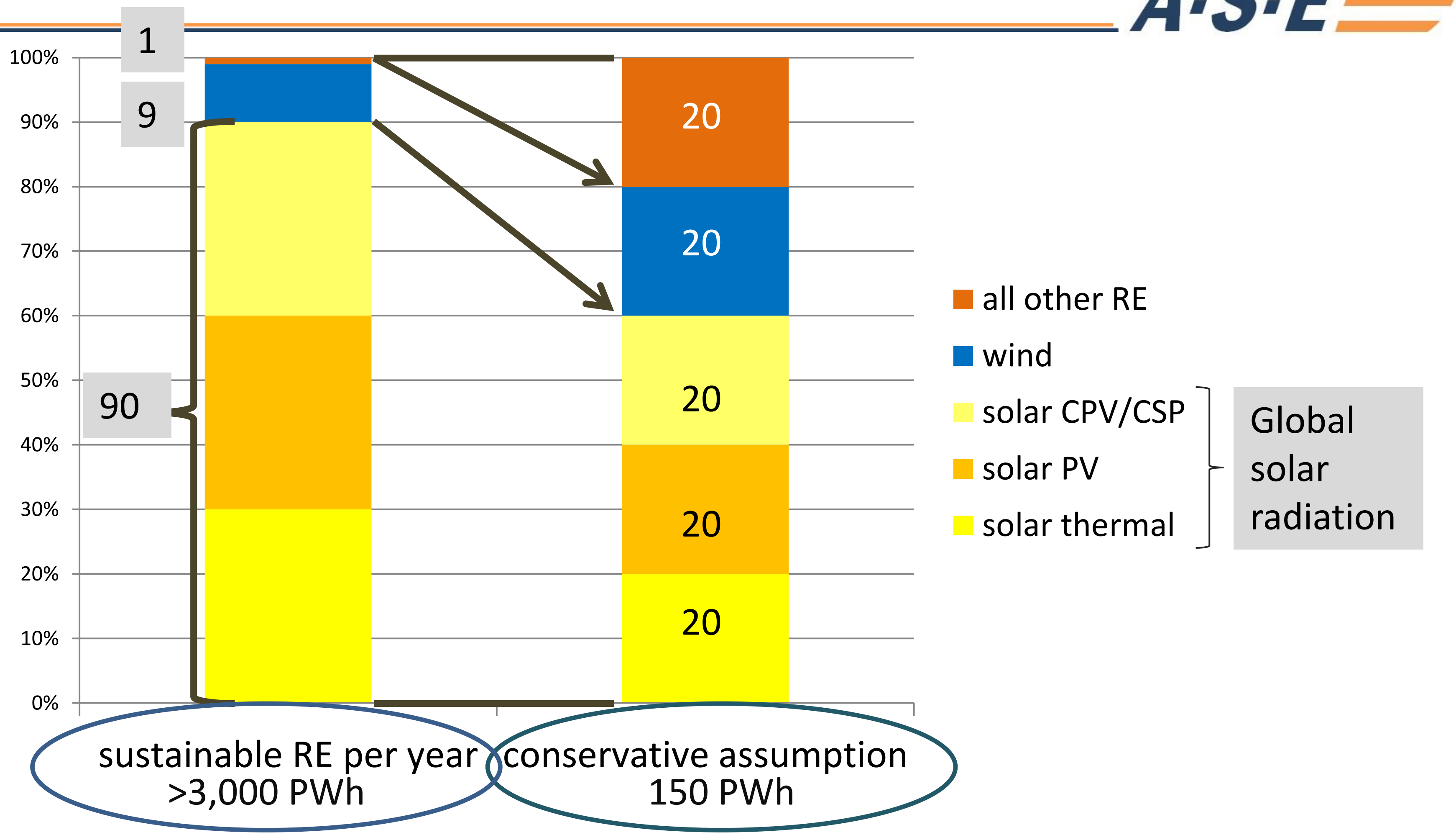
Source: Winfried Hoffmann, 10/2017, eigene Recherchen

Ample evidence that PV and wind are least cost and price producers for electricity

Big remaining question:
Is the industry able to provide timely the necessary renewable energy converters?

Source:

Annual sustainable potential for RE and conservative assumption



Source: WBGU, 2011 (left column);Winfried Hoffmann, own estimates (right column)

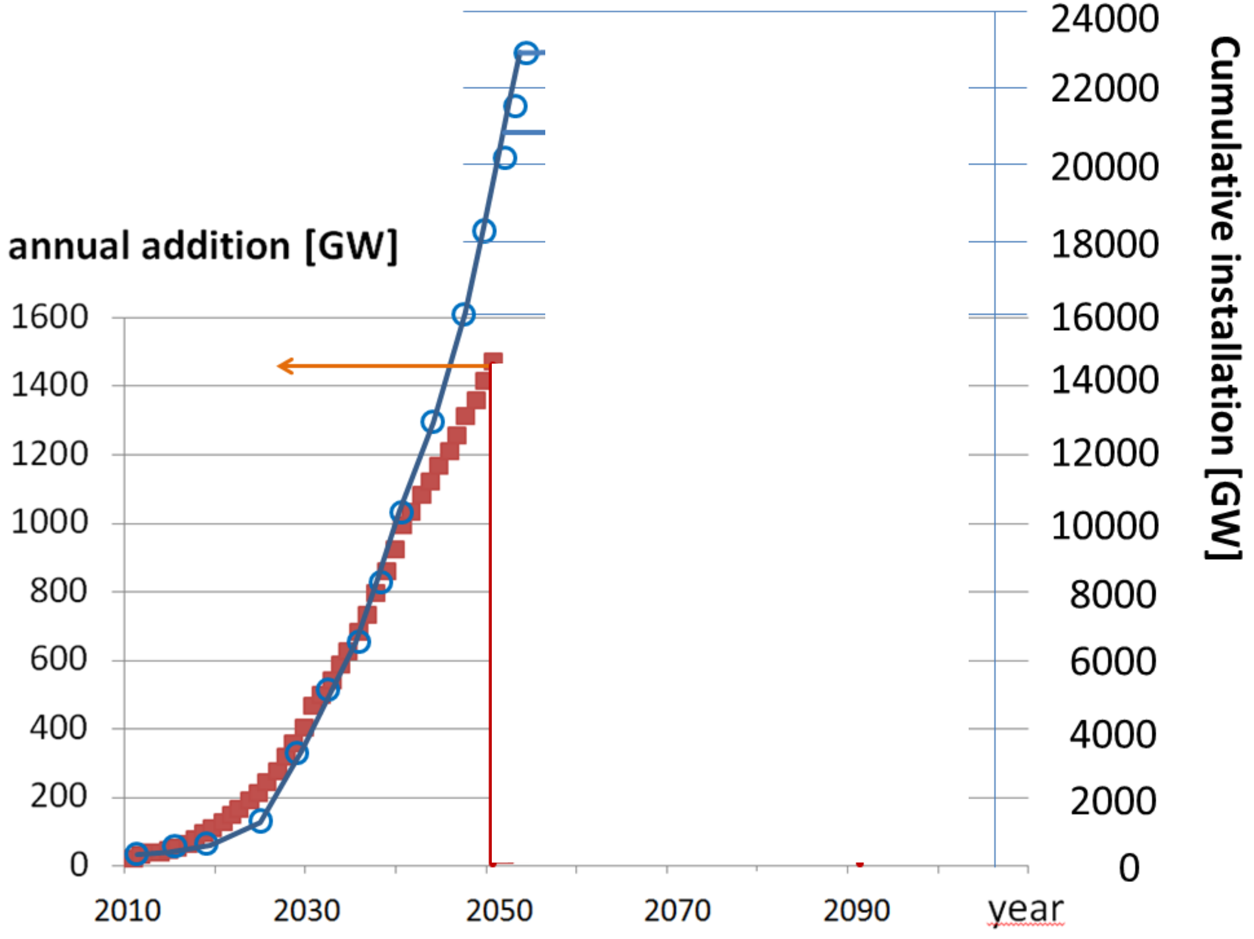
… how realistic is a 20% PV share for the future 100% RE annual SE?

	V 1	V 2
Decade	% growth	p.a.
1990 - 2000	*20*	*20*
2000 - 2010	*50*	*50*
2010 - 2020	20	20
2020 - 2030	14	15
2030 – 2040	8	10
2040 – 2050	4	5
cumulative PV power in 2050 [TW]	**23**	**30**
Annually produced energy [PWh] in 2050 at 1.3 kWh/W (average)	**30**	**38**

…quick & dirty exercise …

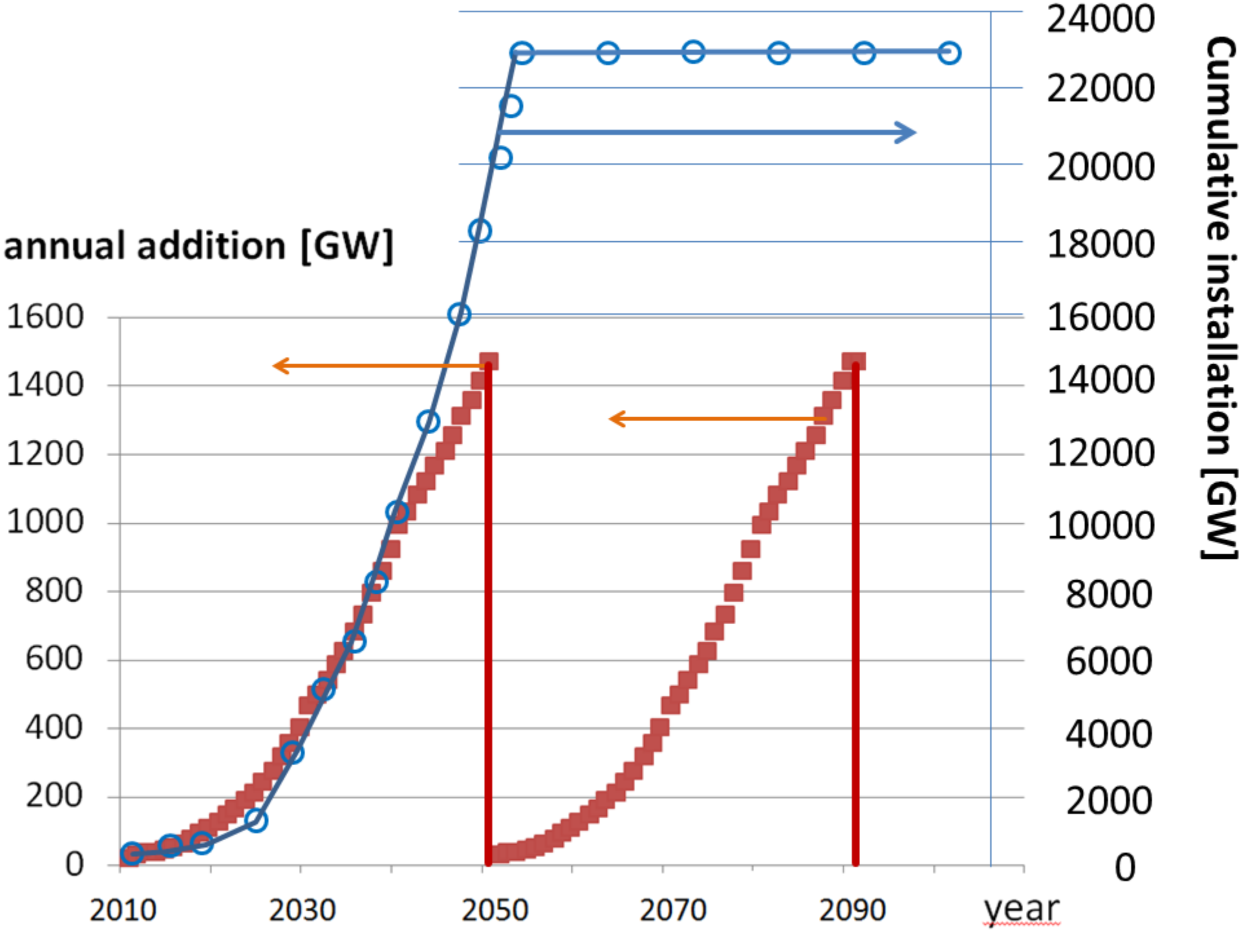
Source: Winfried Hoffmann, own data

Oversimplified growth to reach 23 TW cumulative PV installations (40 years lifetime assumed)



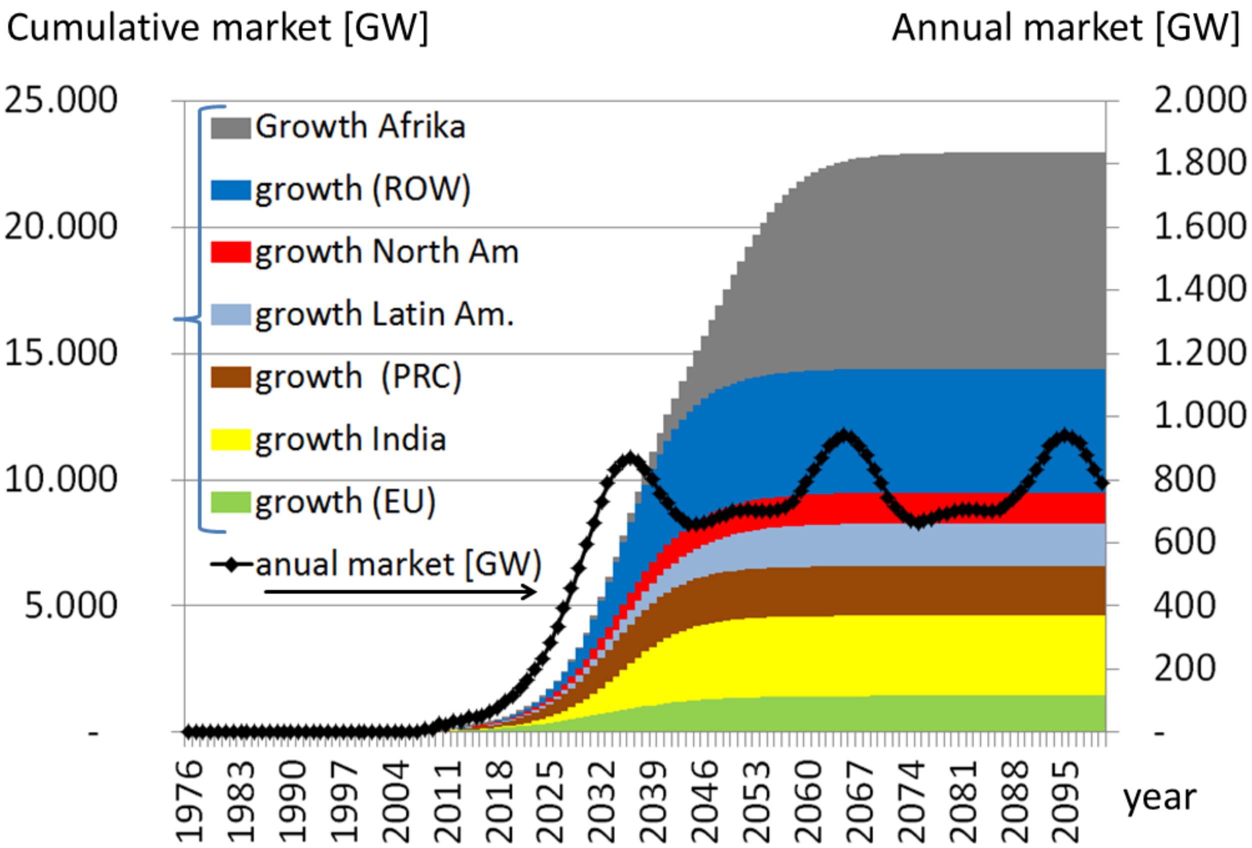
Source: Winfried Hoffmann, 2010

…quick and dirty exercise to demonstrate realistic feasibility to reach 23 TW cumulative PV installations in 2050



Source: Winfried Hoffmann, 2010

Realistic logistic growth curve to reach 23 TW (30 years lifetime assumed)

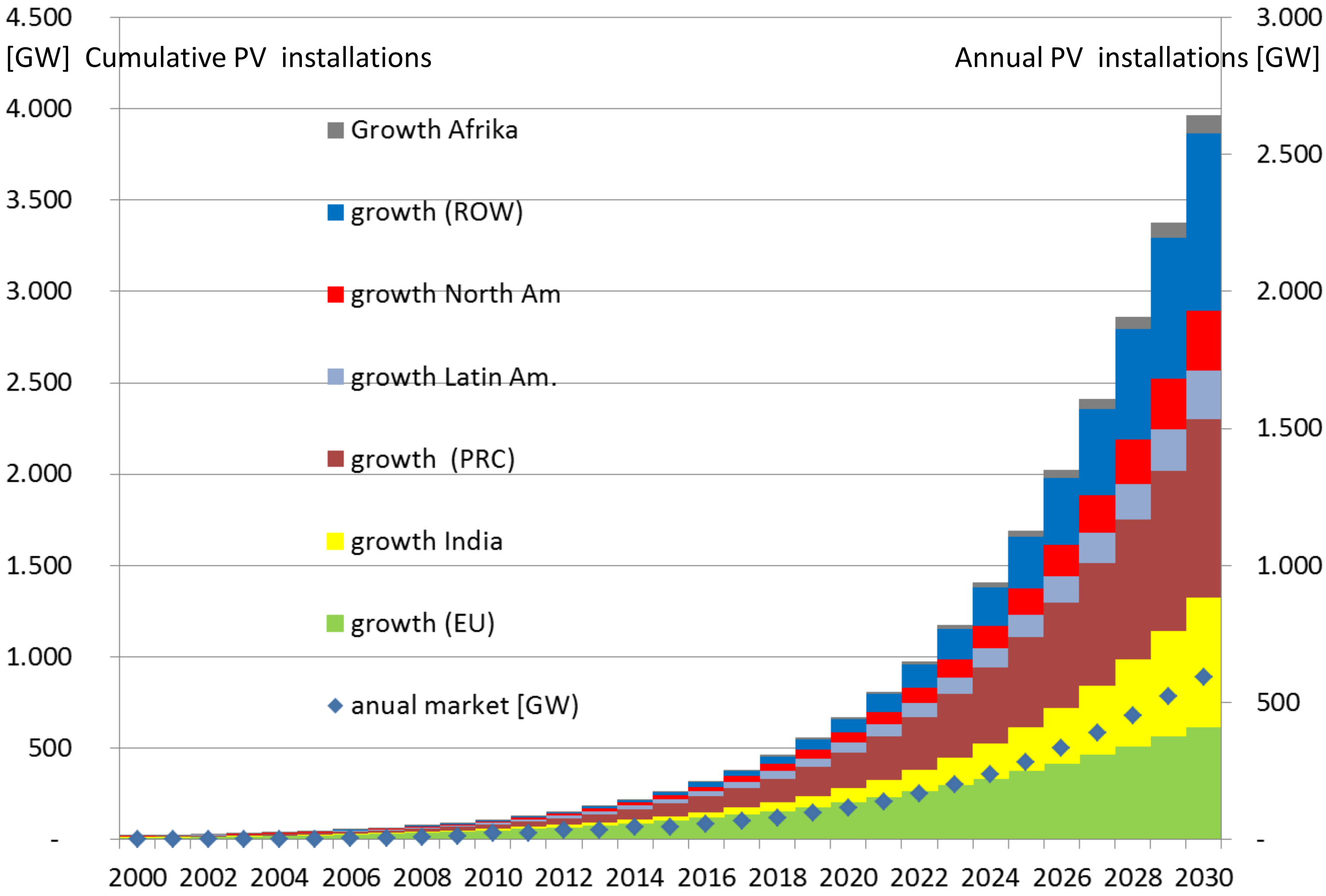


$N_i(t) = G_i/(1+\exp(k_i(c_i-t)))$

i respective growth area
G_i cumulative PV inst.
in 2050+ in region i
c time constant, when
90%+ from G is reached
k growth slope

Source: Data by Winfried Hoffmann (2015), calculation of logistic growth curve by Markus Fischer (Hanwha Q-Cells GmbH (2015)

…up to 2030 in more detail …



Quick check:

Algeria has firm plans to install 22 GW RE by 2030; assume 11 GW by PV

40 m people in Algeria and ~1.2 bn in Africa

→ 330 GW would correspond in Africa if the same growth were as Algeria

→ In our graph there are „only“ ~100 GW for Africa in 2030

Source: Data by Winfried Hoffmann (2015), calculation of logistic growth curve by Markus Fischer (Hanwha Q-Cells GmbH (2015)

Necessary Growth Rates to Reach the 5 x 30 PWh RE Goal

	~2010+/-		~ 2050+			
	GW	TWh	TWh	PWh	TW	CAGR [%] p.a.
Photovoltaics	~100	~120		~30	~23	+ 14.8 +16%
CPV/CSP	~ 1	~ 2		~30	~17	+ 27.2
Solar thermal	~190	~130		~30	~44	+ 14.5
Wind	~280	~600		~30	~10	+ 10.3
Bioenergy	-	~14,000	↓ ~10,000	~30		substitute
Hydro	~850	~3,500	↑ ~8,000		-	+ 2.1
Geothermal, wave&tidal, etc	-	~ 5	↑ ~12,000			+ 21.5
Total	1,421	18,357		150		+ 5.4

..from „Solar Home Systems“ in the 1980s to „Pico-PV“ today ..

		light	PV	battery	total	radio	tele	www	refr
1980s	[P]	3 x 25 W	50 W				CRT		
	[E]	x 4h ~300 Wh		0,3 kWh					
	[€]/ unit	x 2 ~6	~x 5= 250	~x1000 = 300	~550			-/-	
2010s	[P]	3 x 5 W	10 W		**1/10**		FPD		
	[E]	x 4h ~ 60 Wh		~0,06kWh		<	<		<
	[€]/ unit	x 5 = ~ 15	~x 1 = ~10	~x 500= ~ 30	~ 55			√	

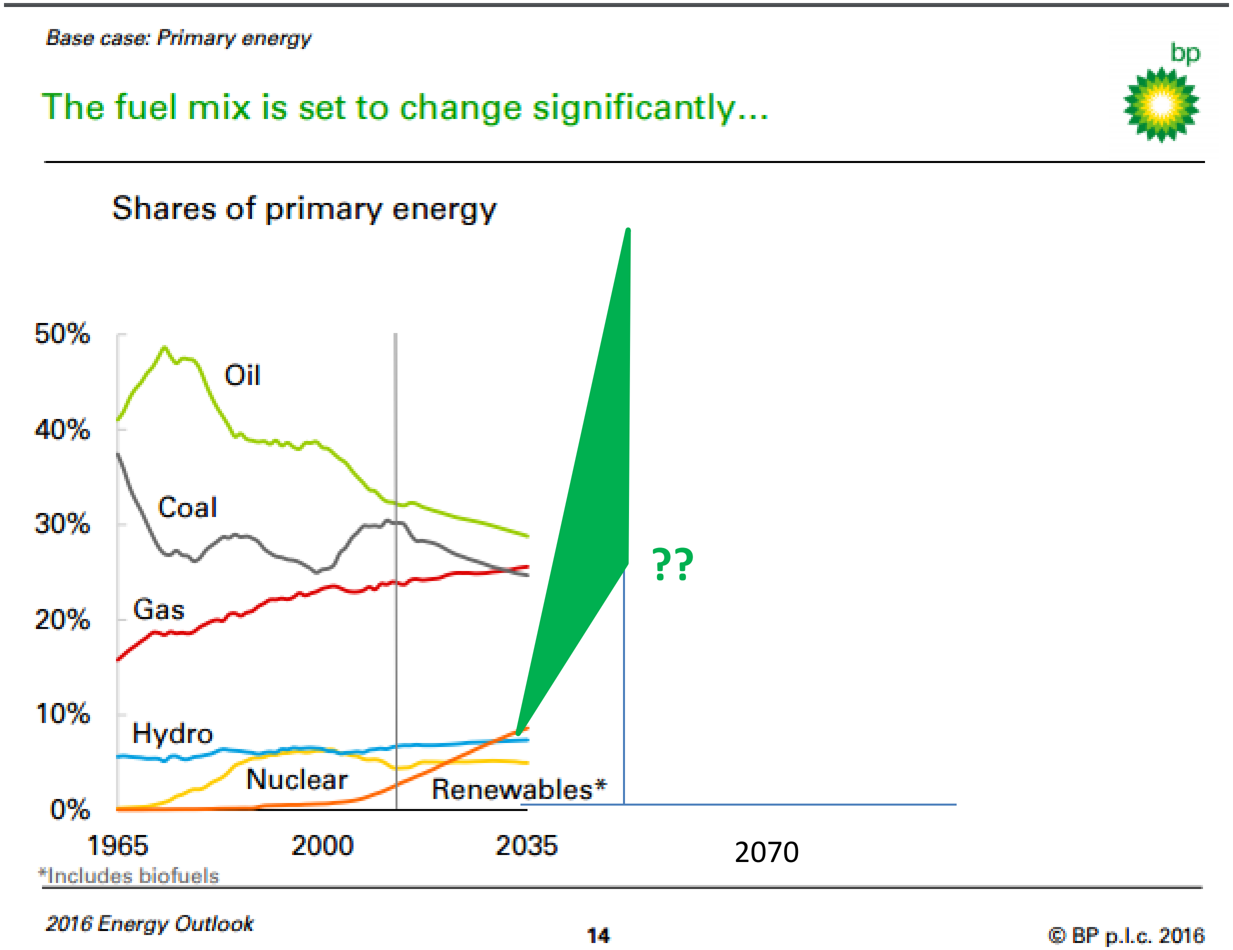
Source: Own data (2016)

BP Energy Outlook
2016 edition


Outlook
to **2035**

bp.com/energyoutlook
#BPstats

BP's Energy Outlook (1)



Base case: Primary energy

bp

The fuel mix is set to change significantly…

Shares of primary energy

*Includes biofuels

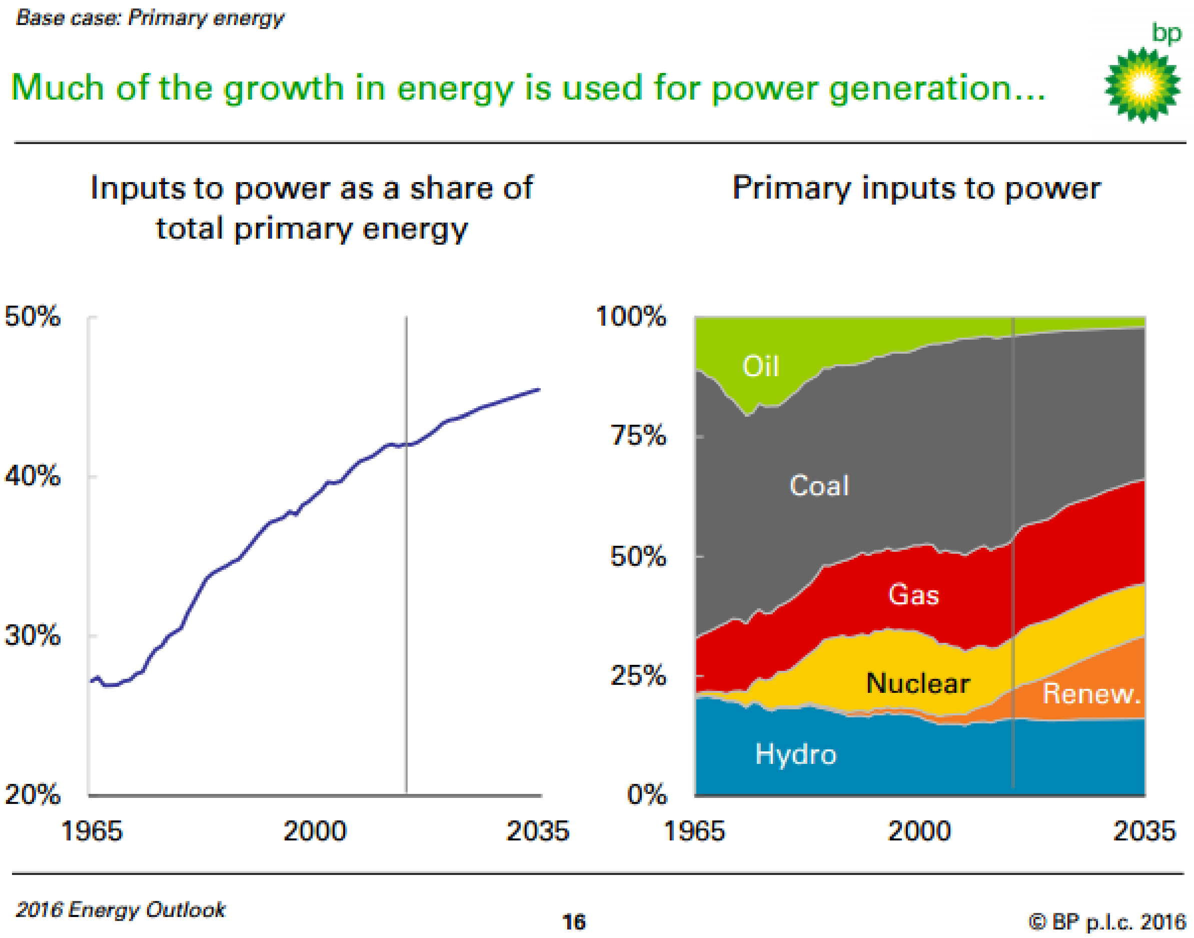
2016 Energy Outlook

14

© BP p.l.c. 2016

Source: BP Global Energy Outlook 2016, green area by W. Hoffmann

BP‘s Energy Outlook (2)



Base case: Primary energy

Much of the growth in energy is used for power generation…

Inputs to power as a share of total primary energy

Primary inputs to power

2016 Energy Outlook

16

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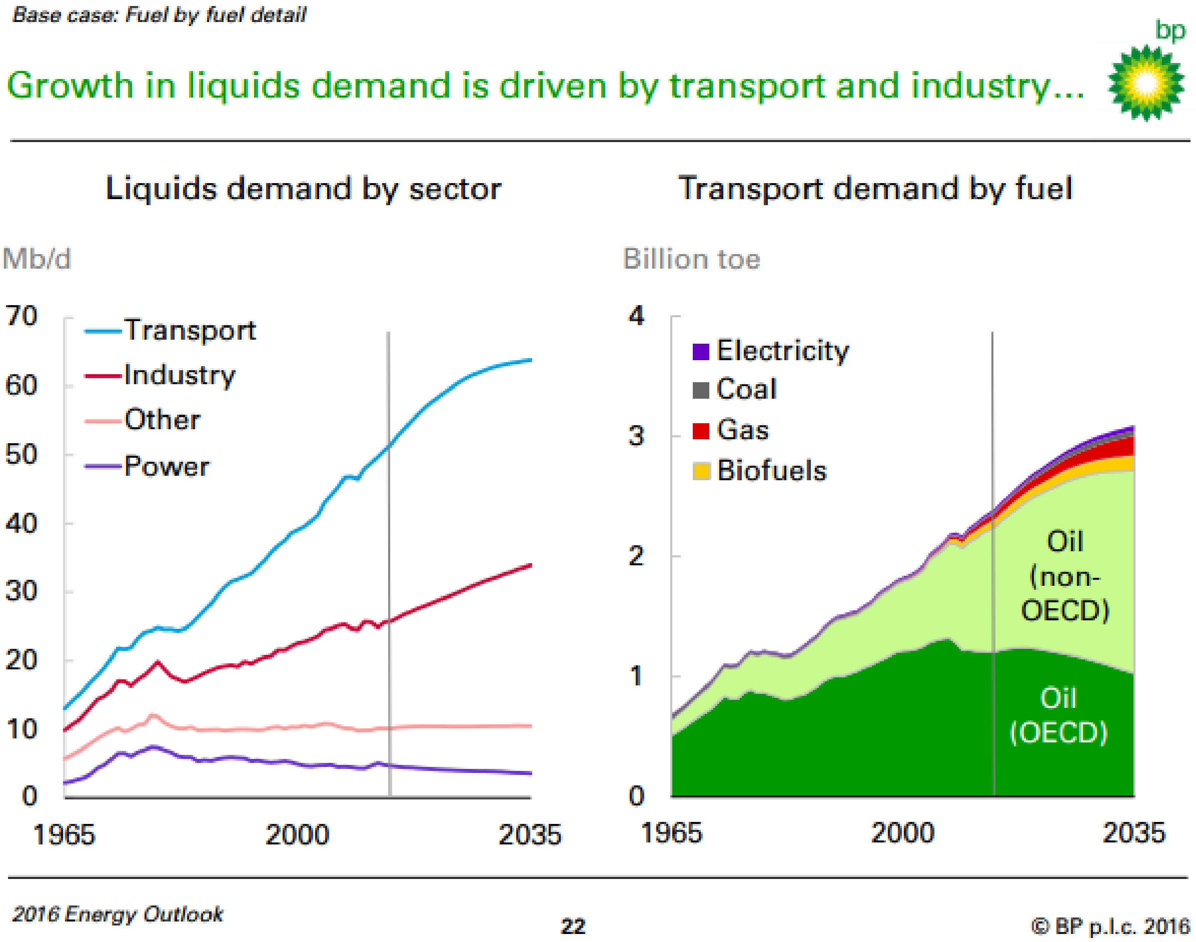
Source: BP Global Energy Outlook 2016

BP‘s Energy Outlook (3)



Base case: Fuel by fuel detail

Growth in liquids demand is driven by transport and industry…

Liquids demand by sector

Transport demand by fuel

2016 Energy Outlook

22

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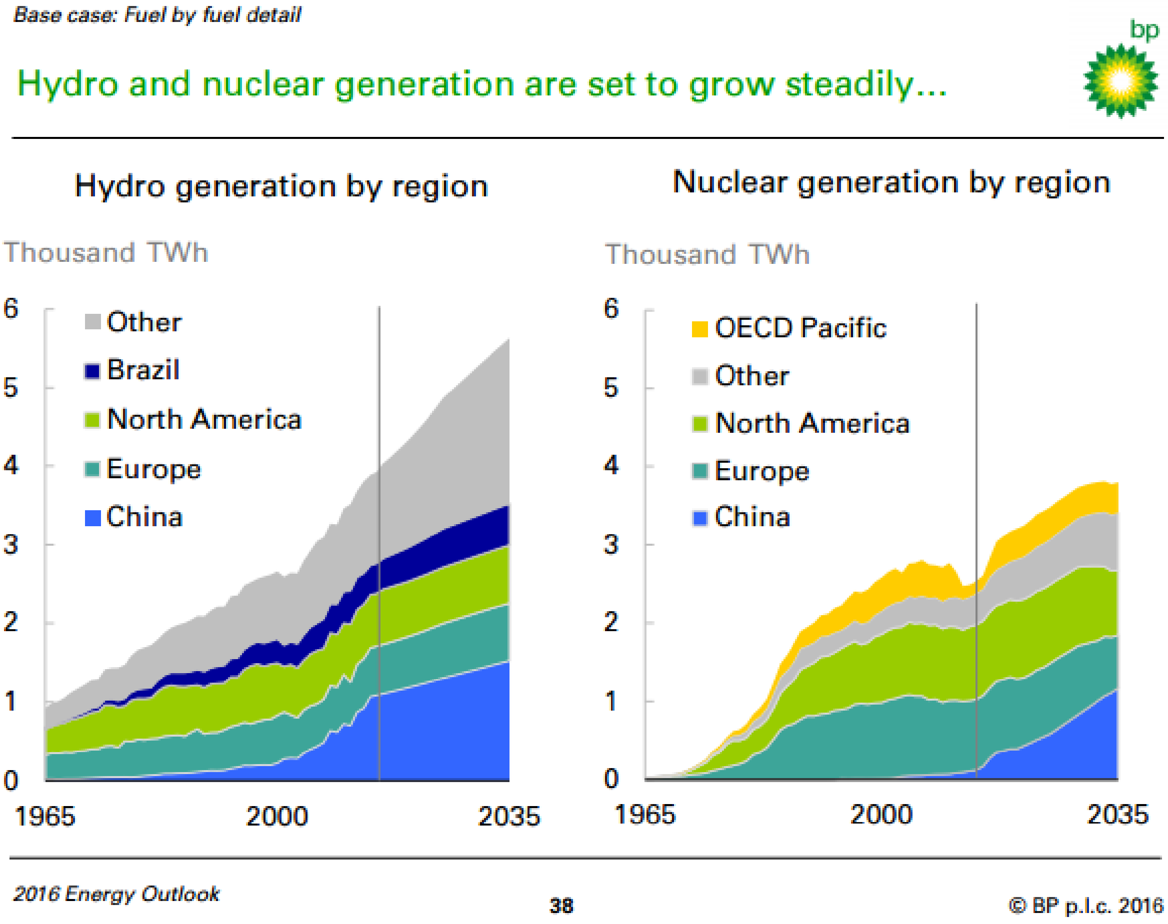
Source: BP Global Energy Outlook 2016

Obviously BP does for the transport sector almost not see electric cars by 2035 !

→ This is in sharp contrast to other projections

BP‘s Energy Outlook (4)



Base case: Fuel by fuel detail

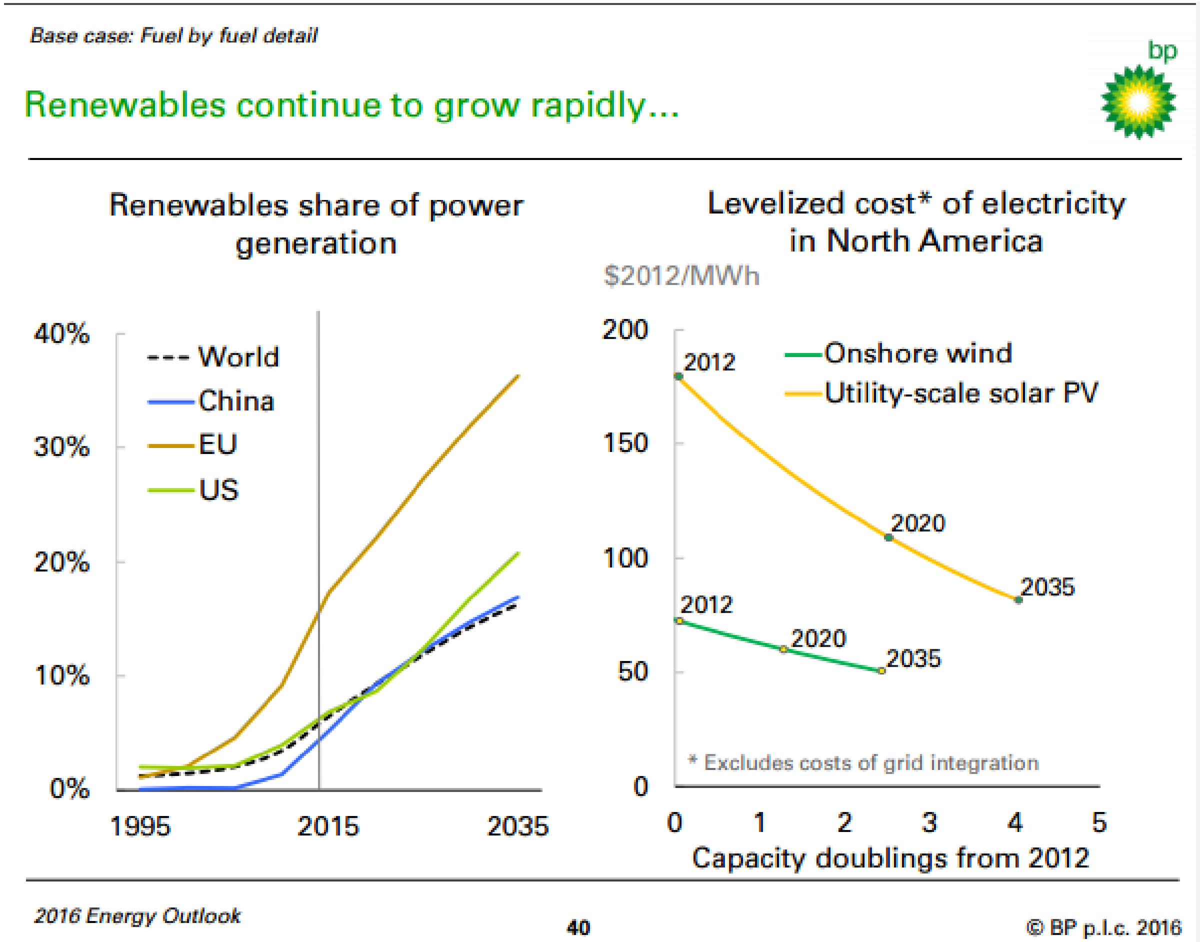
Hydro and nuclear generation are set to grow steadily…

2016 Energy Outlook 38 © BP p.l.c. 2016

Source: BP Global Energy Outlook 2016

BP‘s outlook	WHff
For hydro	
~ 4 PWh in 2016	~4
~ 5.5 PWh in 2035	~5
For nuclear	
~ 2.4 PWh in 2016	~2.4
~ 3.7 PWh in 2035	~2

BP‘s Energy Outlook (5)



Base case: Fuel by fuel detail

Renewables continue to grow rapidly…

* Excludes costs of grid integration

2016 Energy Outlook

40

© BP p.l.c. 2016

BP‘s outlook for PV: **W. Hoffm**

2016 ~14 $ct/kWh **3 - 7**

2020 ~12 $ct/kWh **2.5 - 6**

2035 ~ 8 $ct/kWh **2 - 4.5**

→ Dramatic underestimation for PV LCOE
… even for today (2016)!!

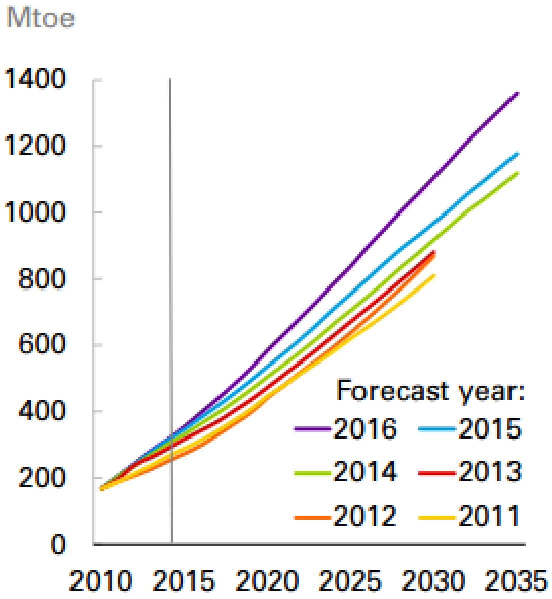
Source: BP Global Energy Outlook 2016

BP‘s Energy Outlook (6)

Base case: Main changes

Renewables have been revised up repeatedly…

Renewable power forecasts



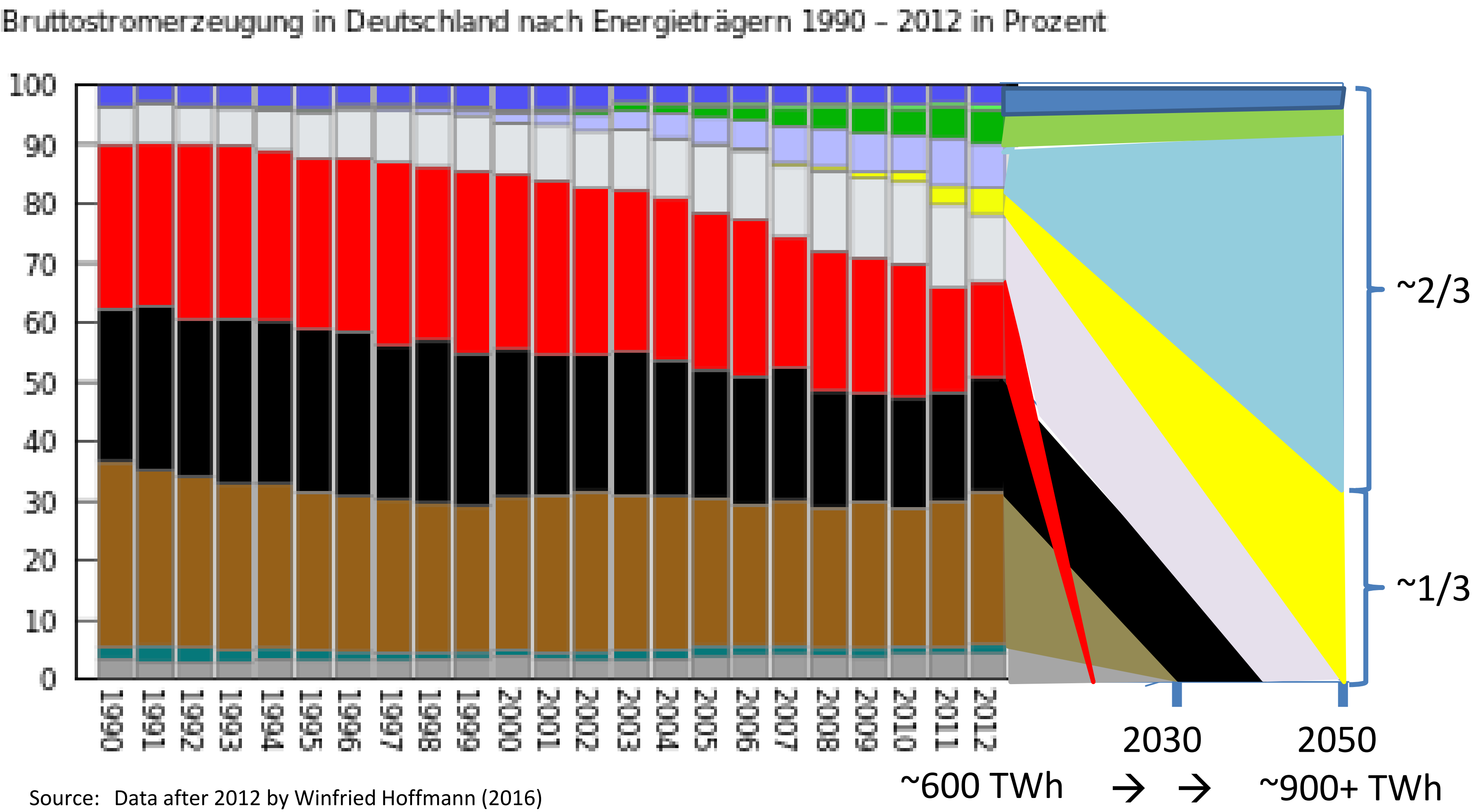
Note: Projected growth from each Outlook applied to latest 2010 data

2016 Energy Outlook 66 © BP p.l.c. 2016

	BP‘s prediction:	**W. Hoffmann forecast:**
2020	7 PWh	**7 PWh**
2035	16 PWh	**~30 PWh**
2050	~26 PWh (Φ = 4.5% p.a.)	**100 PWh** **(Φ= 9.3% p.a.)**

Source: BP Global Energy Outlook 2016

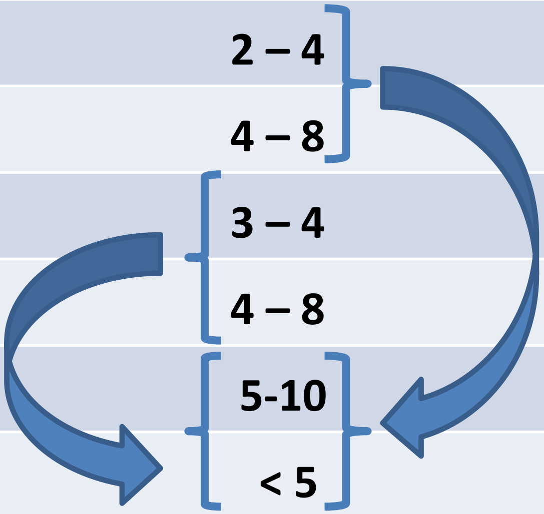
Potential further development for gross electricity production in Germany



Source: Data after 2012 by Winfried Hoffmann (2016)

Longer term electricity price development … 2020/2030

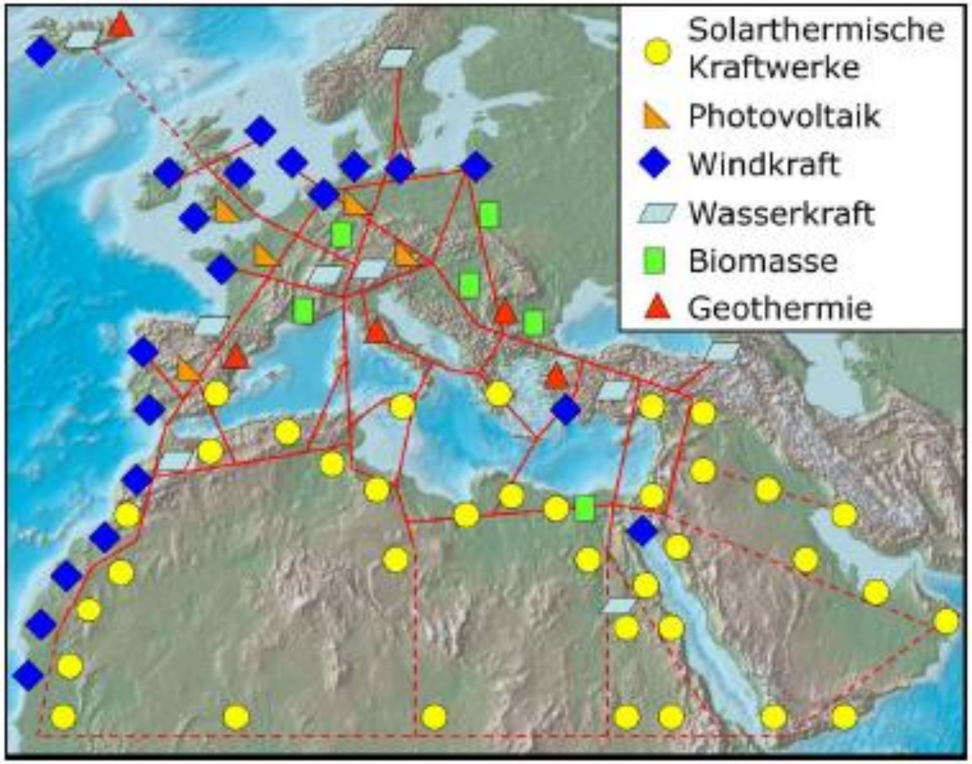
Own	Technology	LCOE in today's currency [$ct/kWh]
Traditional	Clean coal with CSS	> 10
	Nuclear fission	>> 10
Photovoltaics	Southern areas (~2 kWh/W_{PV})	2 – 4
	Northern areas (~1 kWh/W_{PV})	4 – 8
Wind	On-shore (~2 kWh/W_{wind})	3 – 4
	Off-shore (~4 kWh/W_{wind})	4 – 8
Storage	Small (~kWh+)	5-10
	Large (~MWh)	< 5



Source: Own data

DESERTEC

Concept Combines Deserts and Technologies



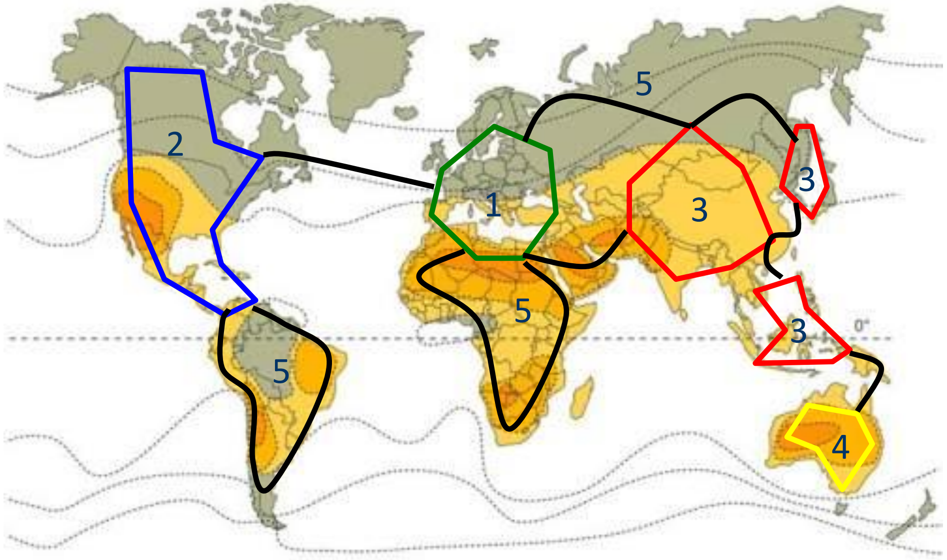
…the network is OK, however:

- ❖ STC supervalued
- ❖ PV hopelessly undervalued
- ❖ Biomass for electricity is nonsense

Concept originally was in my point of view misused by utilities and energy companies to convince politicians NOT to install PV and wind now and everywhere but ONLY to use solar where the sun is mostly shining („desert regions“) and the wind is most blowing („off-shore“) and wait until the network is installed …!

The World Wide Super Grid

- my personal favourite until 2012 -



Source: Solar Millennium AG, Erlangen

■ excellent ■ good ■ suitable ■ not suitable
...for Solar Thermal Power Plant

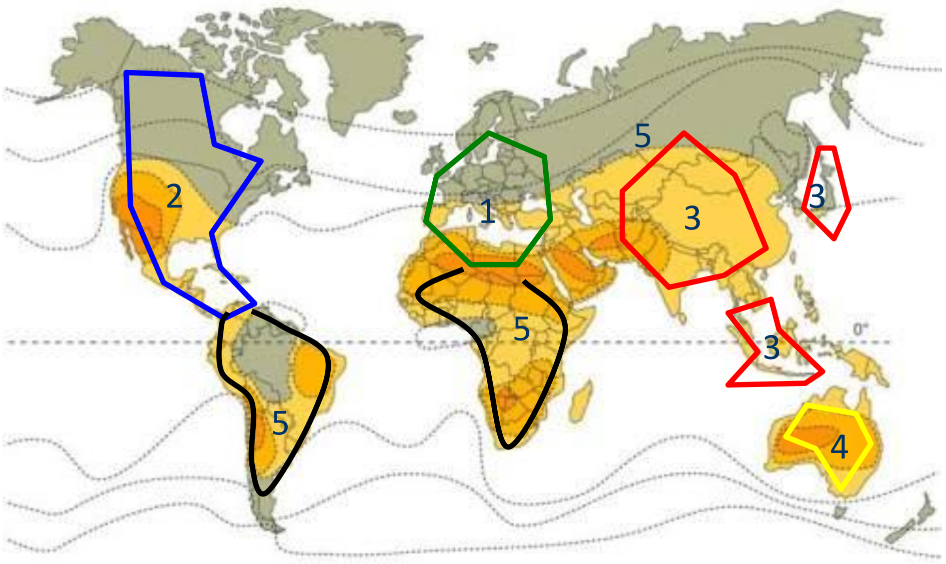
1	🟩	Super Grid	„EUMENA“2010 - 2050	
2	🟦	Super Grid	„NAFTA“	2020 - 2060
3	🟥	Super Grid	„ASIA“	2030 - 2070
4	🟨	Super Grid	„AUSTRALIA“	2040 - 2080
5	⬛	Super Grid	„WORLD WIDE“	2050 - 2100

- **Electricity**
  - wind off-/ on shore
  - Solar Thermal Power Plant
  - PV Solar Electricity
  - Other Renewables
- **Hydrogen**
  for special purposes
- **Solar Thermal**
  for heating and cooling

ref: W. Hoffmann SCHOTT Solar, Alzenau

Local autonomy for a quicker 100% renewably powered world (*)

- my personal view starting from 2013 … -



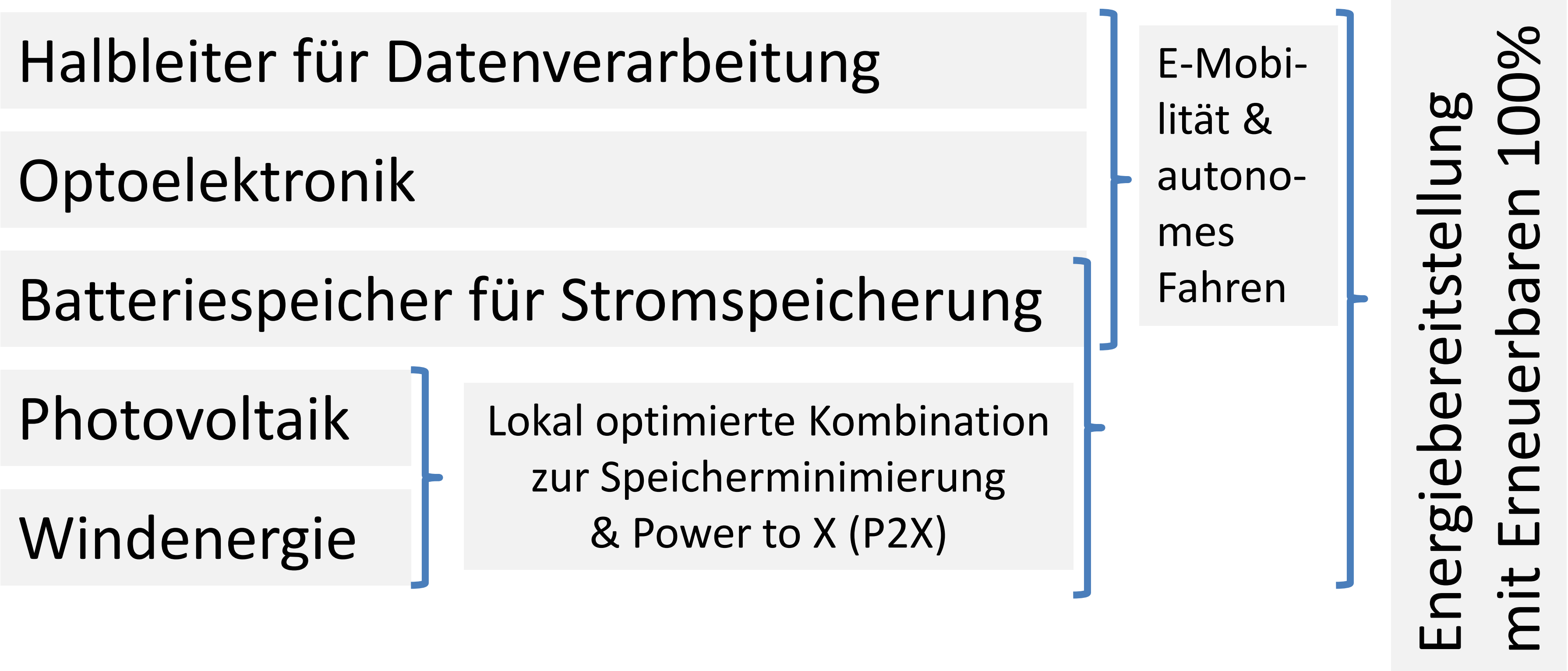
🟧 excellent 🟧 good 🟨 suitable ⬛ not suitable
…for Solar Thermal Power Plant (vice versa for wind)

(*) it also allows more flexibility for regions to either more quickly or more slowly to move towards 100% renewables

- Local autonomy, based on optimization between storage capacity and electricity exchange
- Heavy industry either to locate near places with CPV, hydro or CSP, alternatively HVDC lines to connect production and usage of electricity intensive industries

Source: Winfried Hoffmann, own considerations

Koinzidenz mehrerer sich ergänzender „Break-Through“ - Technologien



Halbleiter für Datenverarbeitung

Optoelektronik

Batteriespeicher für Stromspeicherung

Photovoltaik

Windenergie

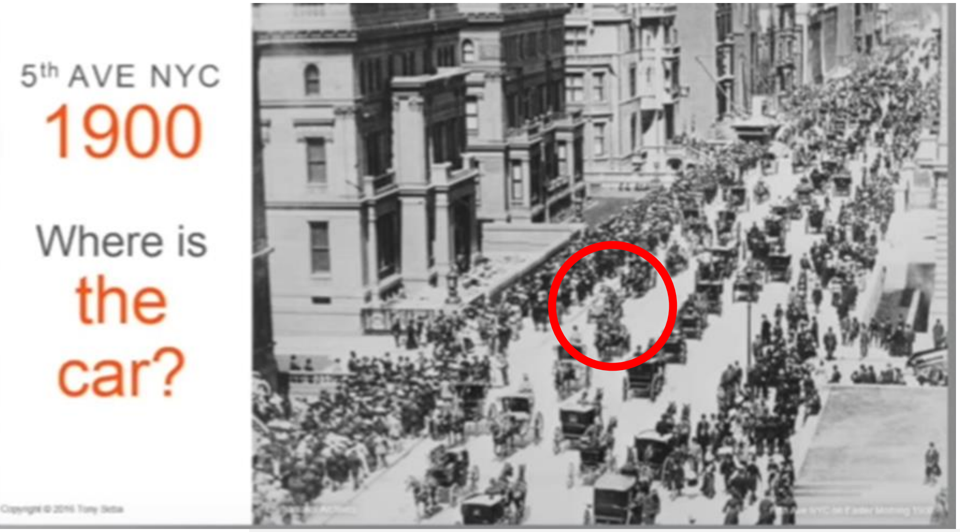
Lokal optimierte Kombination
zur Speicherminimierung
& Power to X (P2X)

E-Mobilität & autonomes Fahren

Energiebereitstellung
mit Erneuerbaren 100%

→ Sehr schnelle Durchdringung des weltweiten Marktes

Disruption (by Tony Seba)



5th AVE NYC
1900

Where is the car?

5th AVE NYC
1913

Where is the horse?

George Grantham Bain Collection

Photo: Easter 1913, New York, Fifth Avenue looking north

You Tube: „Clean Disruption:
Energy and Transport“

Source: Tony Seba

Applied Solar Expertise

… and for those who want to read more:

- Book by Wiley-Scrivener
  (author Winfried Hoffmann)
  „The Economic Competitiveness of Renewable Energy – Pathways to 100% Global Coverage“
  (ISBN: 978-1-118-23790-8)

- See also my web-page
  http://www.AppliedSolarExpertise.de