Electricity from the Sun:
A Bright Future Shines on PV

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and

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and : **HSK – Croatian Solar House** - A national Project

Background

Development of solar PV cells&modules

Crystalline Si solar cells – (A very short history of PV)

Development of science&technology in 21st century

Thin Film Solar Cells (CdTe, CiS, CIGS, a-Si:H ...)

Solar Materials Aspects, Technological Aspects

Social Aspects, Market & Price Aspects....

y. 2009 development in PV

y. 2010 development in PV: **Present state of the art**

Emerging new solar cells technologies

Outlook for the Future (in EU and the world)

Conclusion

1) Background:

Photovoltaics (PV, as well as other RES) address several broad groups of problems:

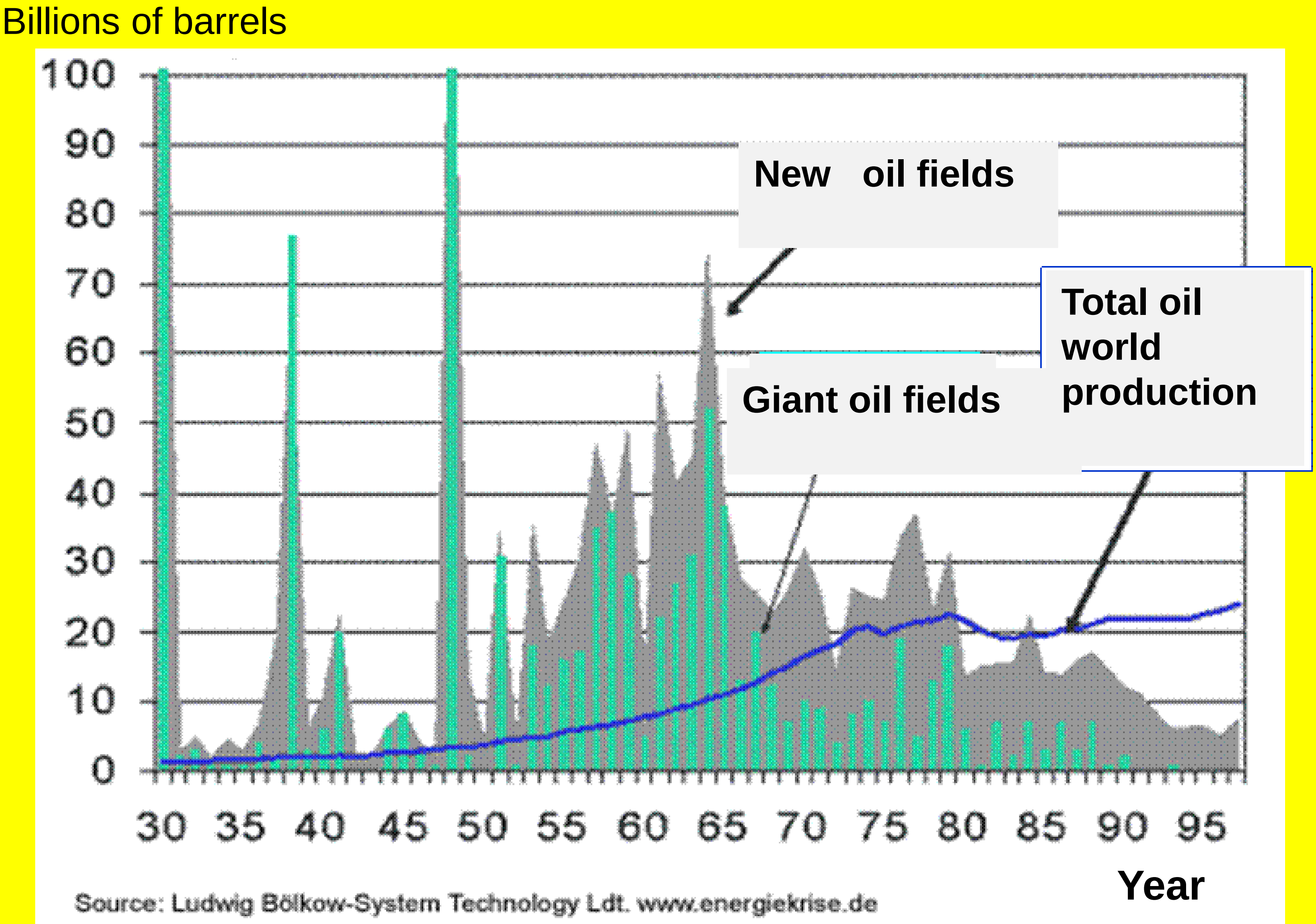
a) Energy Aspect
(Oil as an energy source is nearing to its end)

b) Ecological and Social Aspects - Oil and Coal-based energy sources are very bad pollutants, up to the point to cause climatic changes and peril our civilization

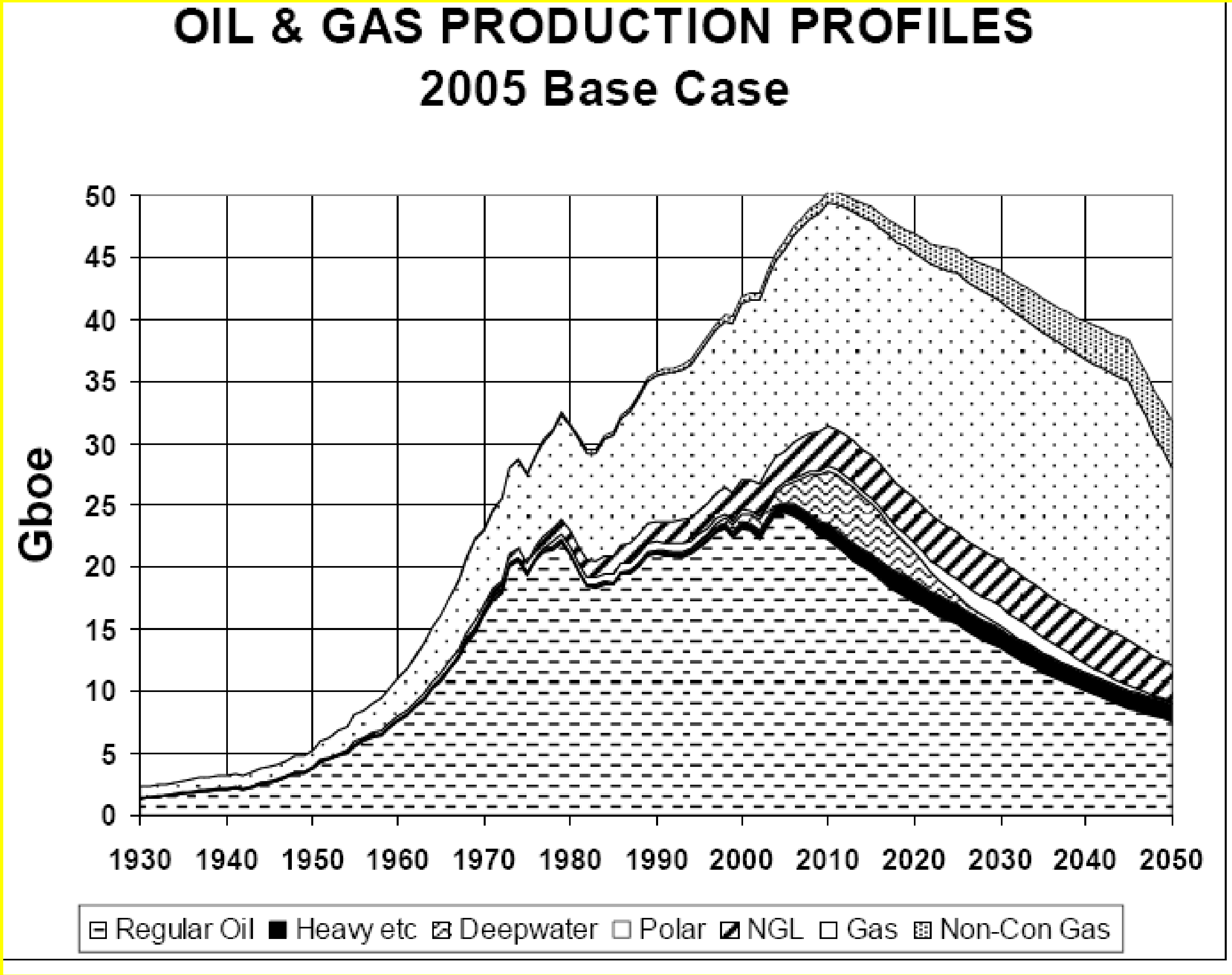
c) Political Aspect – insecurity of energy supply

a) Energy problem – Energy from where?

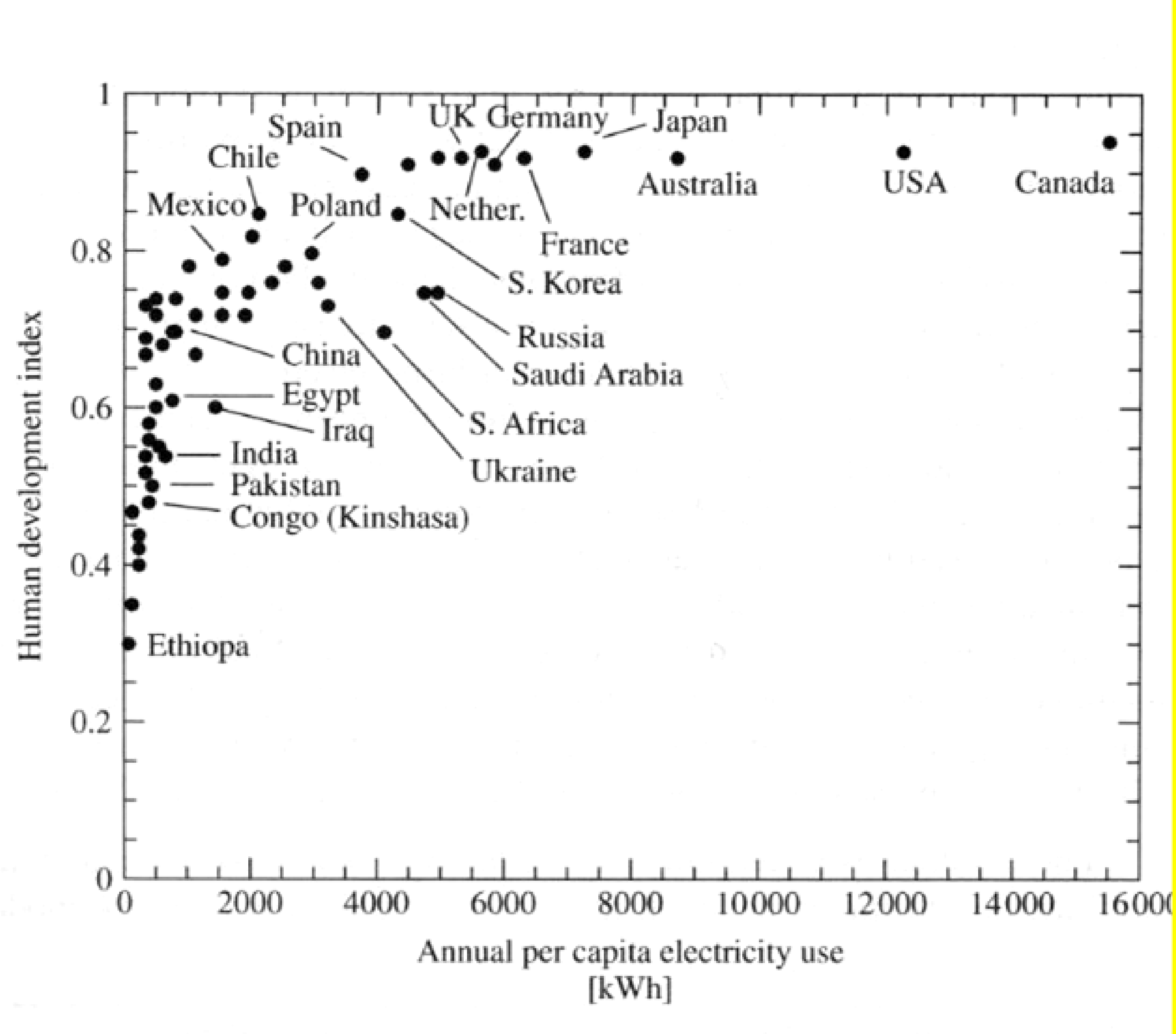
(Oil as an energy source is nearing to its end)



"HUBERT'S PEAK" – the predicted maximum of oil production after what the decline of the oil production is unavoidable



Importance of energy, and electricity in particular



Source: Cornell University

Unfortunately, those who use most energy are also those who most recklessly misuse it

Global map of light pollution (from the space):

http://visibleearth.nasa.gov/cgi-bin/viewrecord?5826

b) Oil and Coal-based energy sources are terrible pollutants:

Greenhouse gases from electricity generation:

Energy Source	SOx (gSOx/kWh)	NOx (gNOx/kWh)	C in CO2 (gC/kWh)	C in CO2 from non-generating portion of fuel cycle * (gC/kWh)
Coal	3.400	1.8	322.8	50.0
Oil	1.700	0.88	258.5	50.0
Natural Gas	0.001	0.9	178.0	30.0
Nuclear	0.030	0.003	7.8	7.8
Photovoltaics	0.020	0.007	5.3	5.3

Rational use of Energy – grossly ignored part in the Energy Supply – Energy Consumption Equation

Mostly forgotten or neglected fact:

The cheapest energy is energy which is saved (not spent)

This is an "inglorious" field – un-proportionally little scientific & technological effort (and money) is spent in this field, - a field that **offers tremendous possibility to reduce energy demand** (even without sacrifying living standard)..

In **building sector**, which represents close to 40% of energy demand, potential for savings are tremendous, even by using already known technologies:

For example, building heating needs could be reduced typically a by **factor of 5-10** (in comparison with present-days buildings) by using "Passive House Standard", which would increase building costs not more than 5-8%..

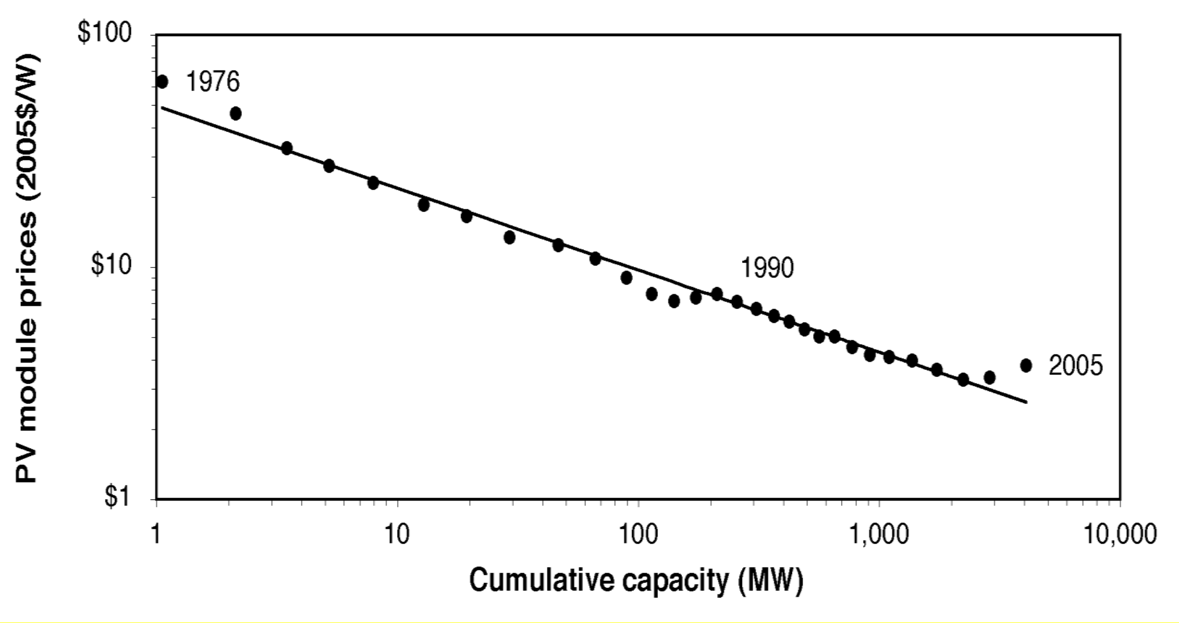
2) PV - a fast-growing contributor of clean electricity to the energy mix of the future

“Photovoltaic” or “PV”:
Direct conversion of sunlight into electricity .
This is the only electricitiy generation that uses a resource that has virtually unlimited potential

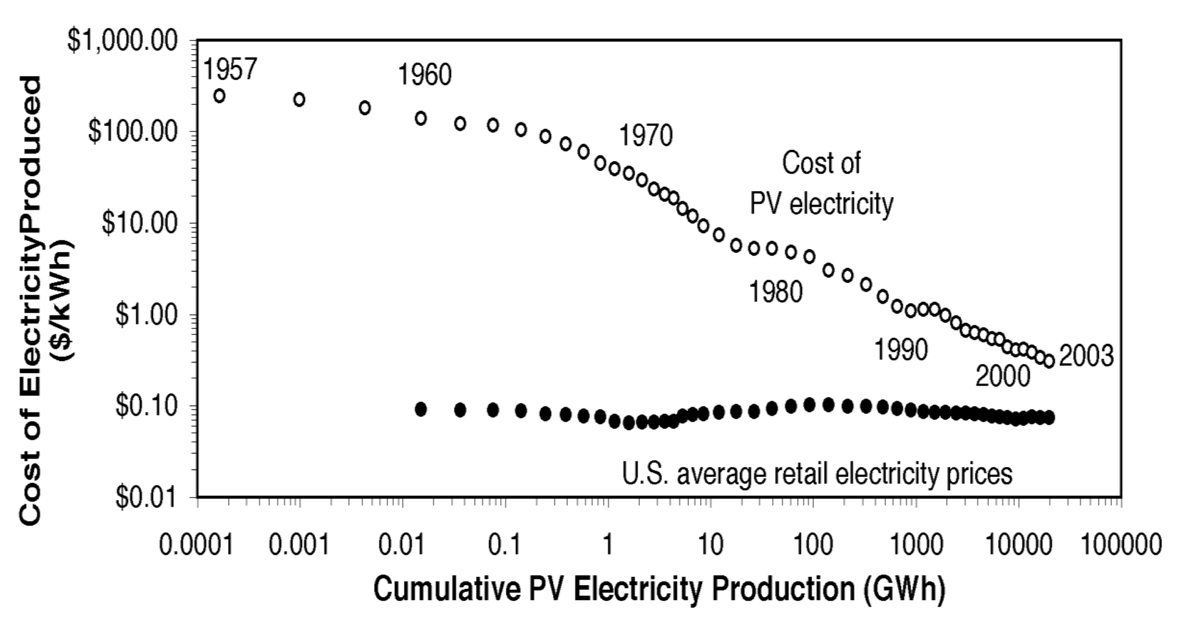
PV is a very stright-forward and elegant process:
PV device works with no emission of any contaminants during electricity production
PV operates silently, there are no moving parts.
Technology is modular and enables gradual expansion as needs are growing (or money becomes available)

The **main disadvantage** is “only” the price but that is shanging dramatically

The "Learning Curve" for PV (c-Si Solar cells)



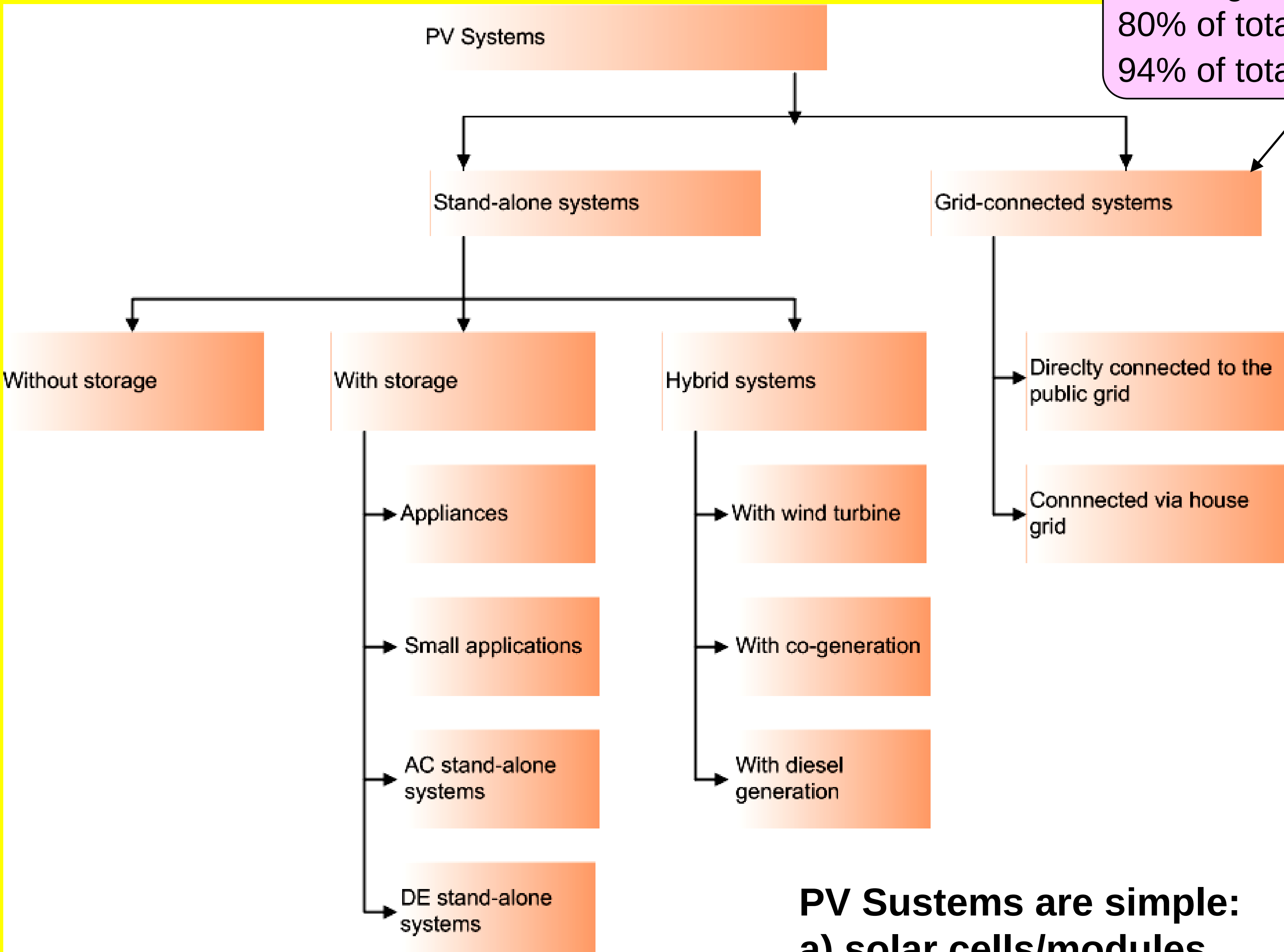
In average, each doubling of Cumulative capacity brings down price for about 20%



Cost of PV electricity was reduced for almost 3 orders of magnitude

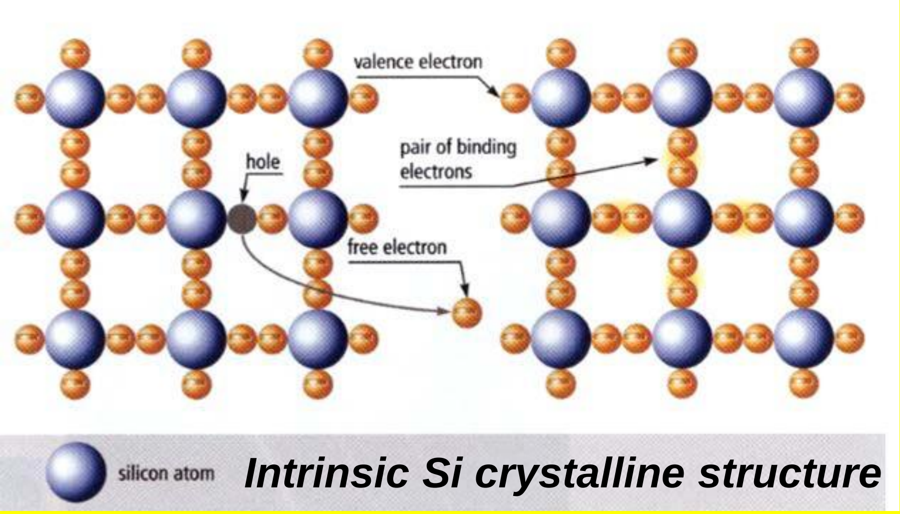
Present uses of Photovoltaics

The largest and growing:
80% of total PV in 2004
94% of total PV in 2008

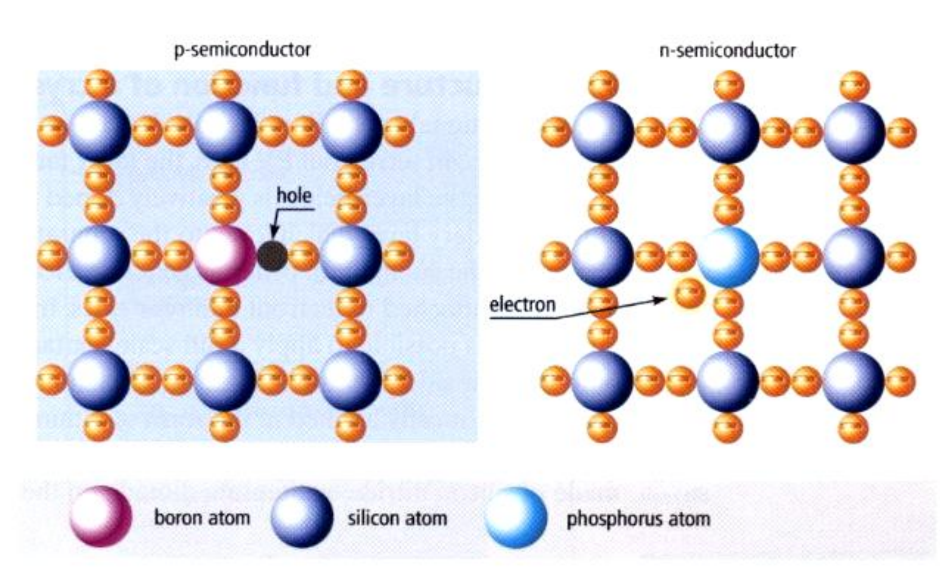


PV Sustems are simple:
a) solar cells/modules
b) the “Balance-of-System” “BoS”).
(electronic components, cabling)

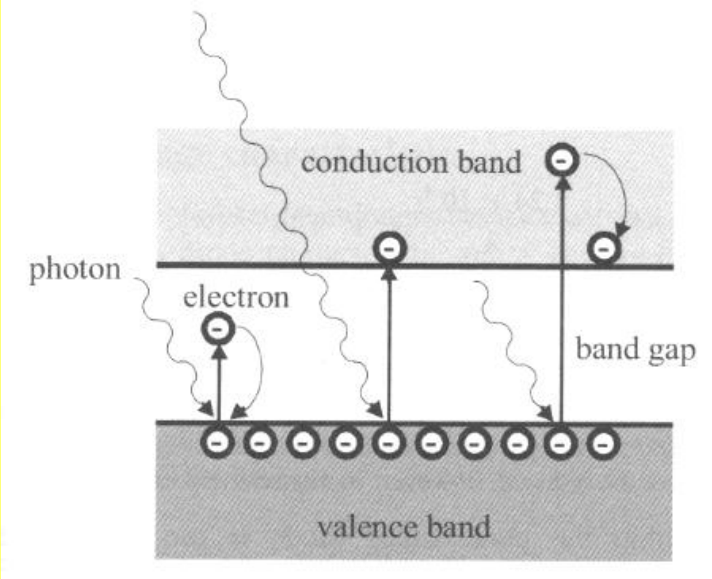
Semiconductor basics



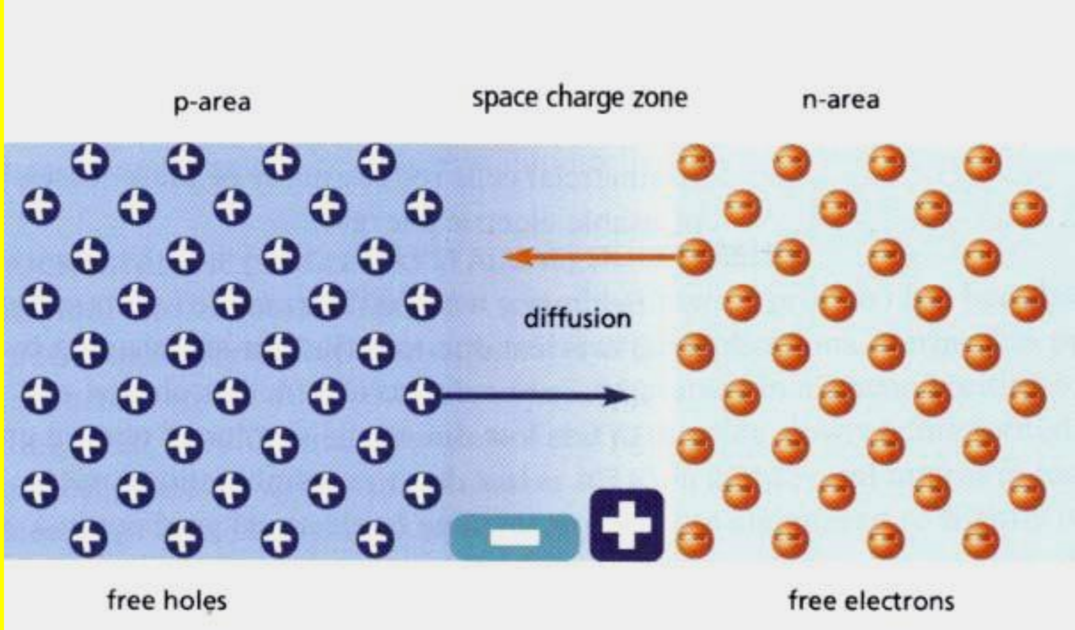
Intrinsic Si crystalline structure



Impurity doping of silicon



Optical absorption is governed by the band-gap



Silicon p-n junction - a built-in electric field

Solar Cell Efficiency

Solar cell efficiency: is ratio of: electrical output power of solar cell, and the optical power of incident solar light; (both measured in (W/cm2)

Many factors cause lowering of solar cell efficiency

a) Loss of solar photons having energy lower than necessary to break bonds between atoms in semiconductors and to create a free electron

b) Loss by excess energy of photons (only one free electron is created, the rest of energy is given to semiconductor as thermal energy
a) and b) - alleviated by using heterojunctions (two or more materials with different bangaps, or nanocrystals (for which band gap depends on nanocrystal size)

c) Loss due to shading of front metal contact — optimized design

d) Loss due to reflection of surface — antireflecting coating

e) Loss by incomplete absorption due to limited thickness of the cell

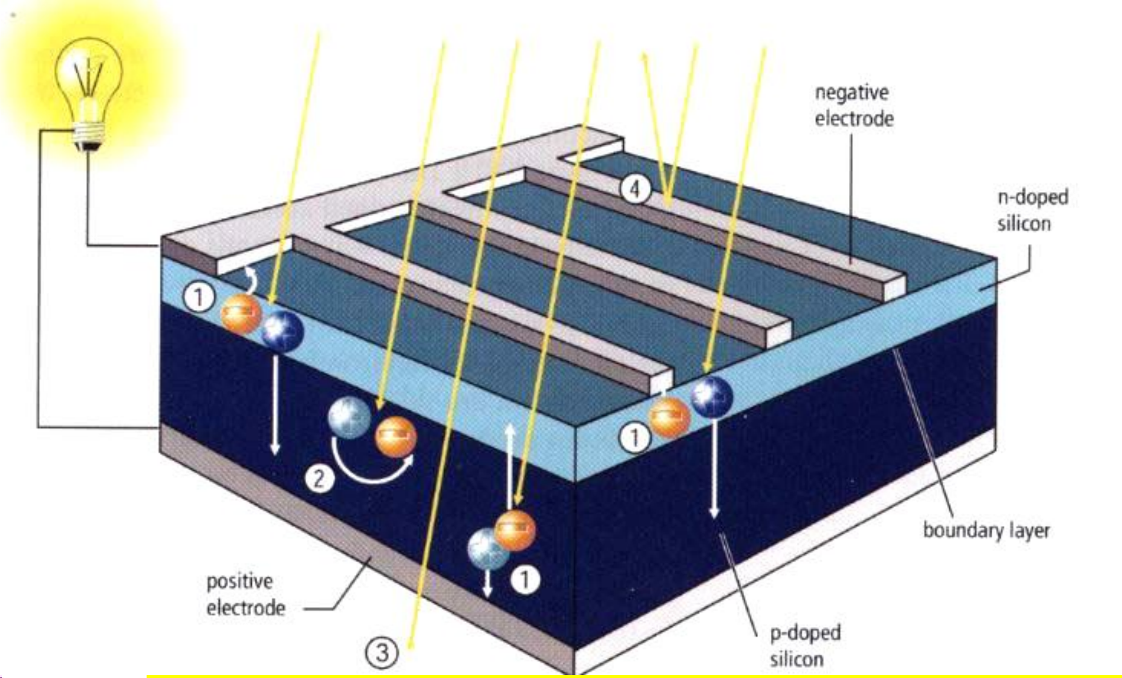
f) Collection efficiency — material quality and its intrinsic properties

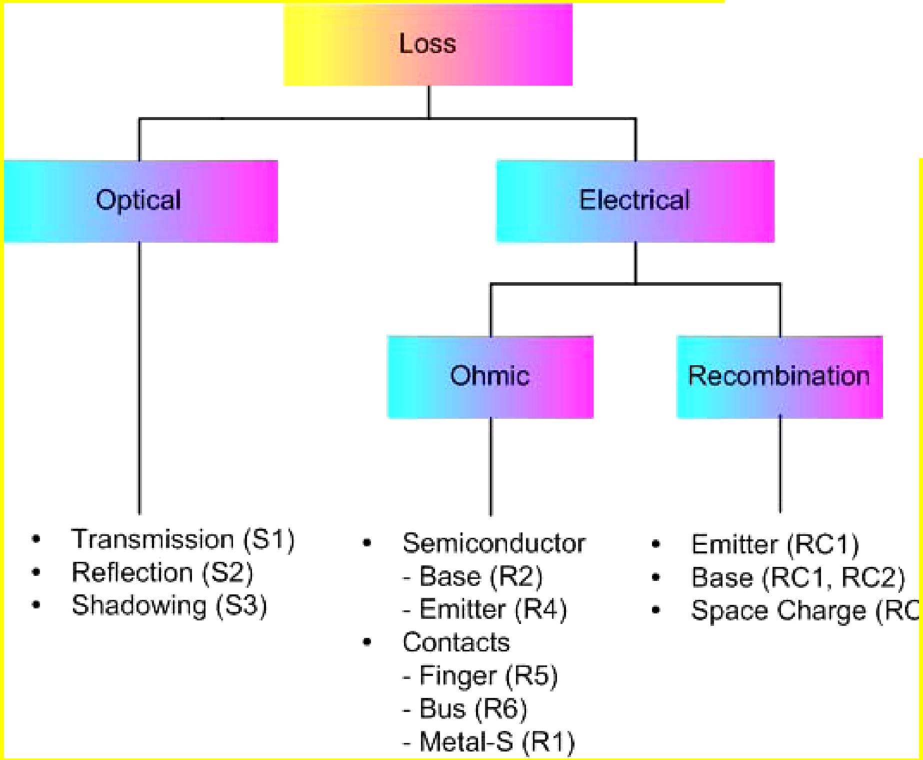
g) Voltage factor — optimized cell production and high material quality

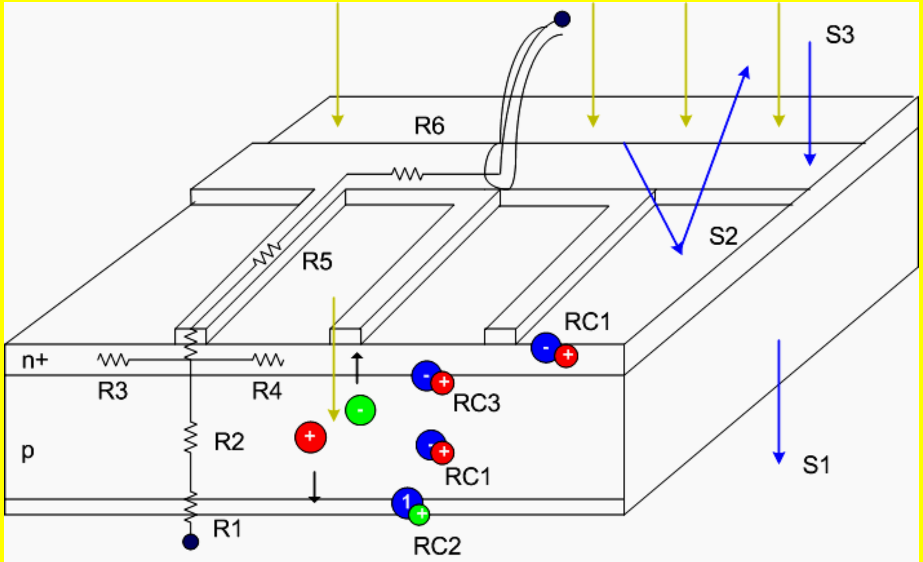
h) Fill factor — optimized cell production and high material quality

Crystalline silicon solar cell

Charge separation (built-in electric field separates electrons and holes created by solar photons)
2. Recombination losses
3. Transmission losses
4. Reflection and shading losses

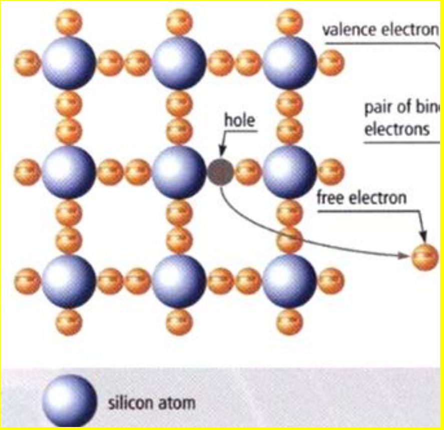


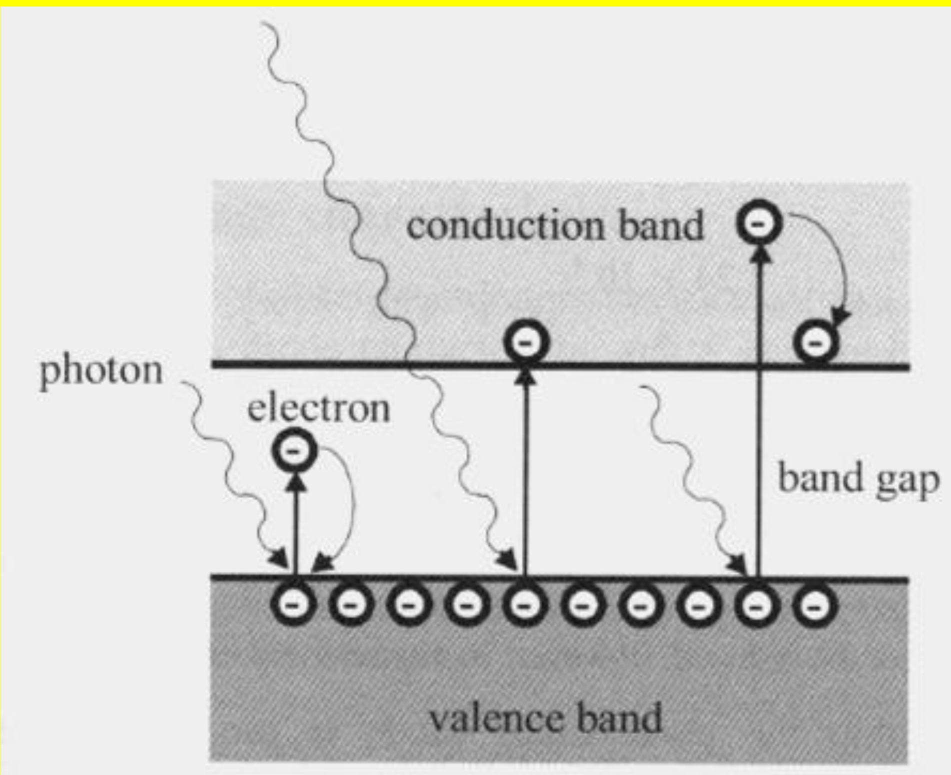




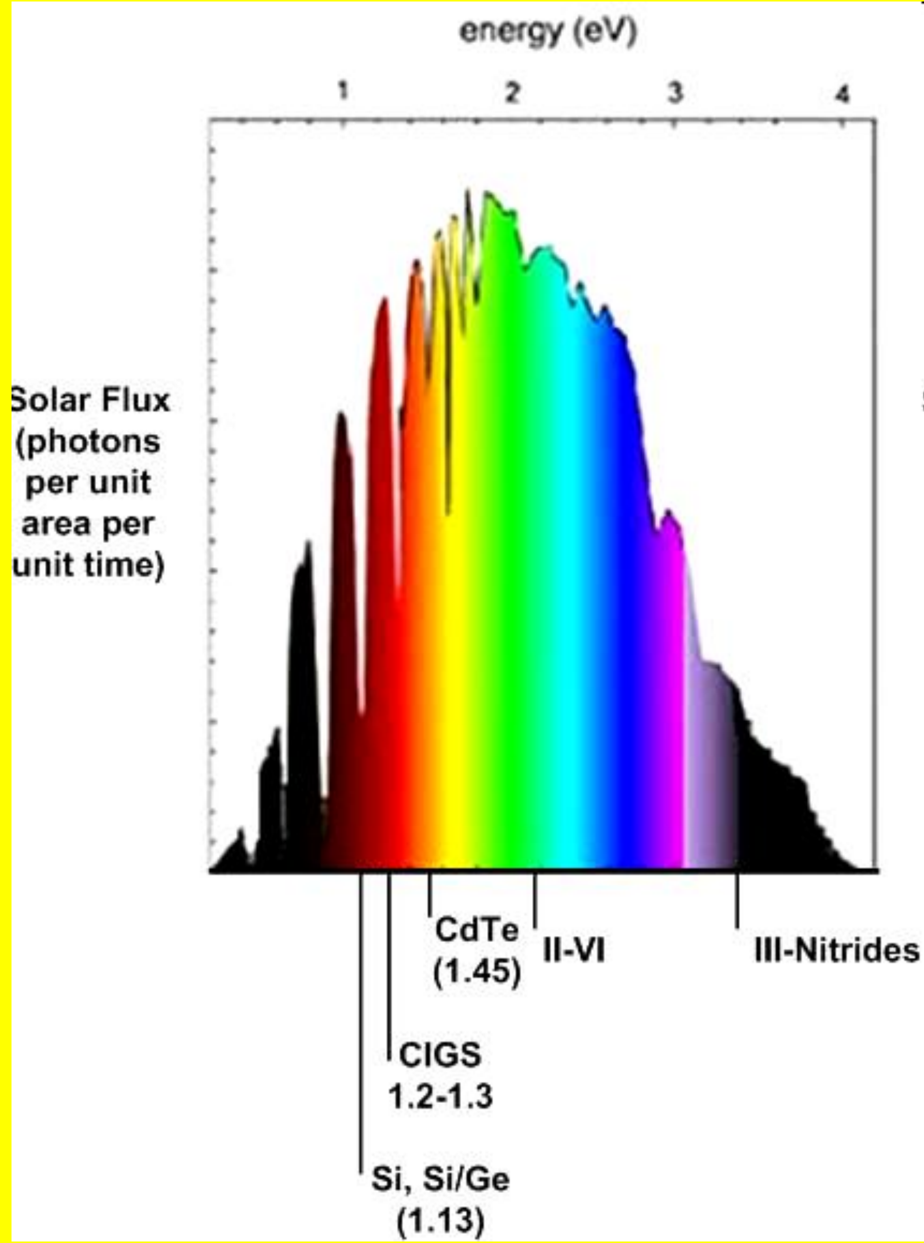
A silicon solar cell has a theoretical top-end efficiency of 29%

Solar Spectrum



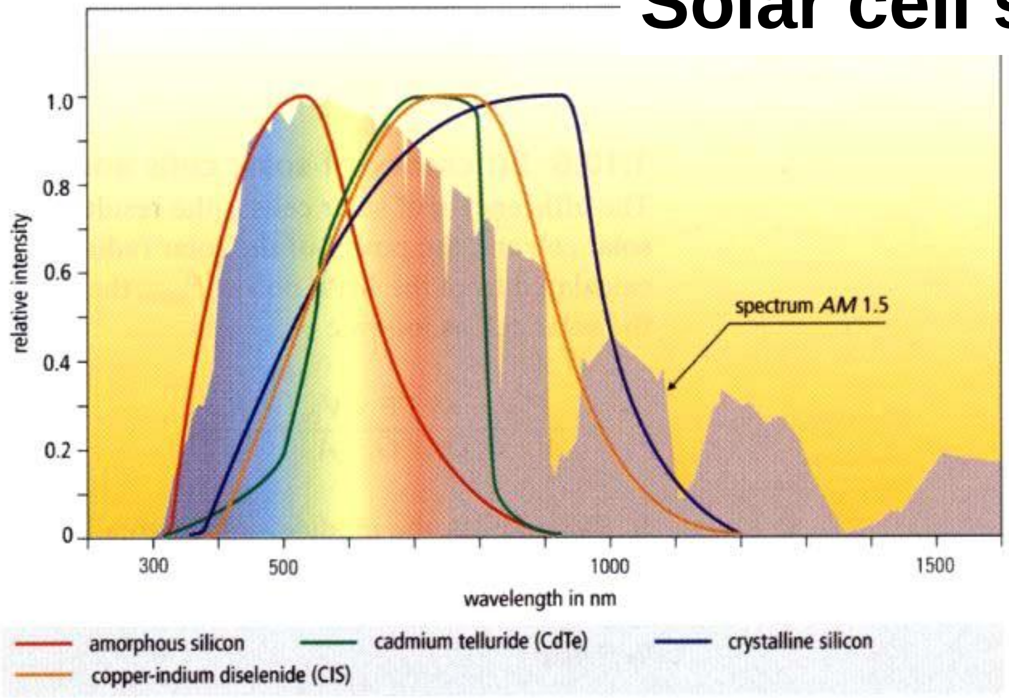


Band-gap is related to energy needed to disrupt lattice bonds and free an electron

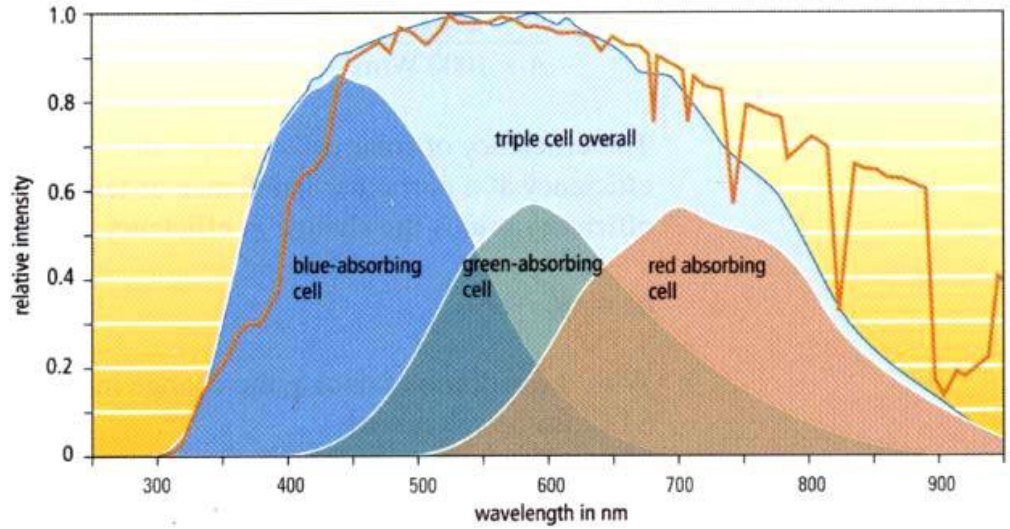


Band-gaps of some solar cell materials in relation with solar spectrum

Solar cell spectral response

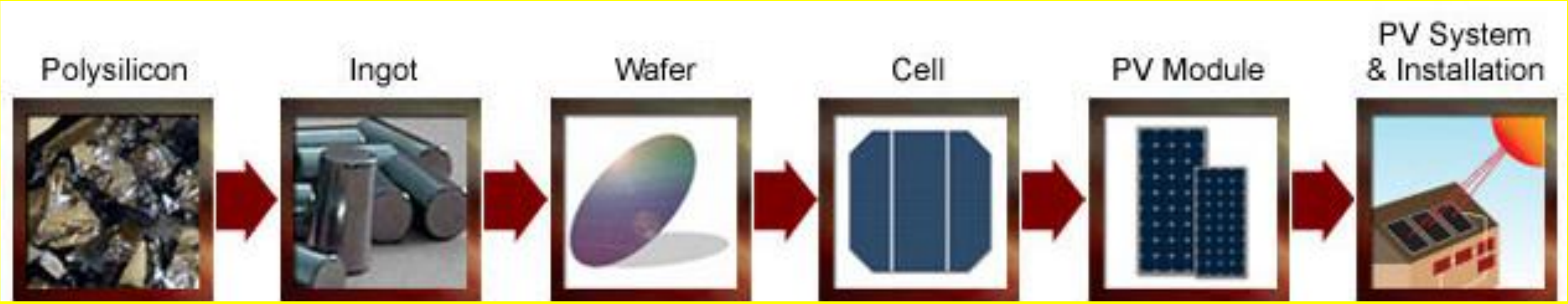


Absorption of solar cells made from different materials (c-Si, a-Si, CdTe, CIS



Better spectral response of cell is to optimize absorption of specific solar bands
- Concept of a tandem cells, heterojunctions, or
- using nanocrystals of differend size

CRYSTALLINE SILICON (c-Si) manufacturing process



The process of producing **polysilicon begins with quartz or sand**, which is refined into **metallurgical grade silicon**,

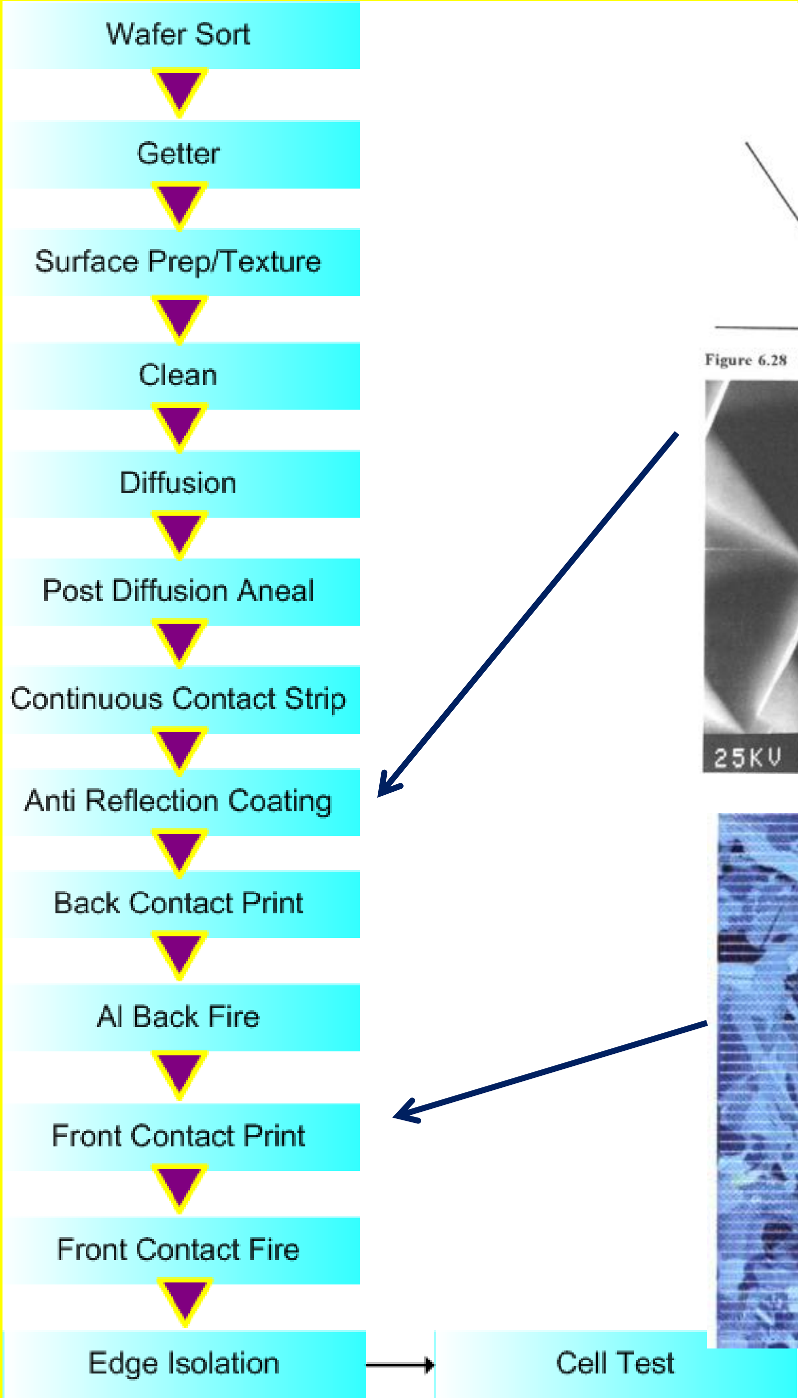
Usually in the Siemens reactor rods **('ingots**') of desired diameter

The **i**ngots sliced and polished into **wafers**

Solar cells: after doping wafers with acceptors and donors, **p-n junction** obtained that separates positive and negative charges (holes and electrones), which are created by absorbing solar light.

Solar cells are wired into **modules**, which are essential part of any PV system

C- Silicon solar cell process



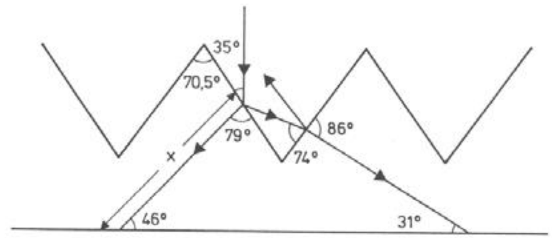
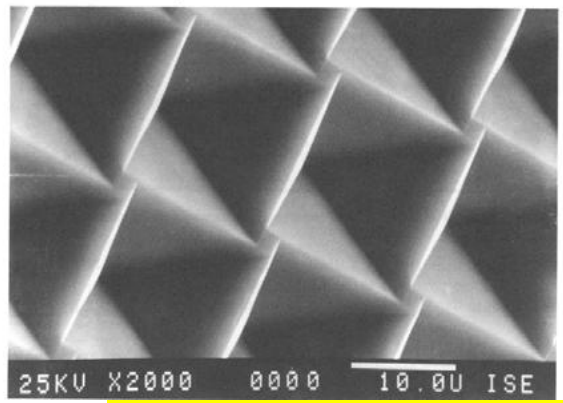


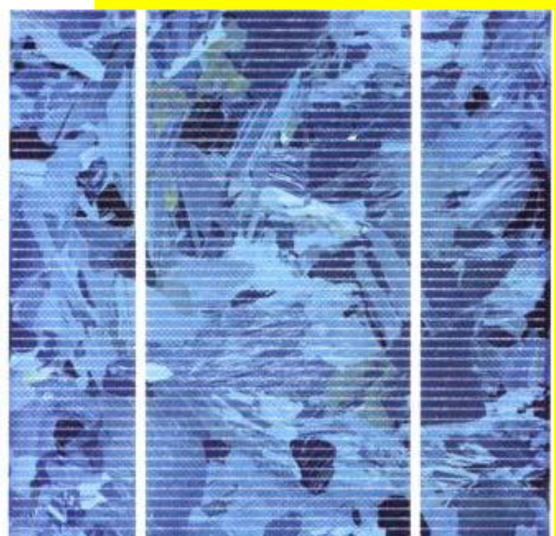
Figure 6.28 Radiation paths for a textured silicon surface



Surface Texturing

- reduces surface reflection

- uniform 'velvet' surface



Multicrystalline cell with screen printed contacts

Crystalline Silicon Solar Cells – Conclusion:

Advantages:

- mature technology, Si is the best know material on Earth
- cell efficiency not very far from maximal theoretical
- module reliability very high
-**cell/module lifetime very long**
- **abundance of raw material**

Useful life-time of best PV c-Si modules is now over 30 years!

(Producer's module warranties of 25 years are nowadays common)

Disadvantages:

- complicated technological proces – less room for large price reductions
-**energy intensive production**
-**Essentially, Si is non-optimal material for solar cells**

Development of PV science and technology in 21st century

Thin Film Solar Cells - general

Thin films solar cells: only few micrometers thick active layer
- sufficient to absorb 90-95% of solar light spectrum -

Thick solar cells (from semiconductors with indirect band-gap, like **c-Si**: necessary thickness for the same absorption: 200 – 400 μm

In year 2005, 95% of solar cells were produced from crystalline silicon solar cells and **only 5% from thin film solar cells (all types).**

In y. 2009, thin film accounted for **22%** of all solar cell capacity**.**

By y. 2013, thin film technologies are forecasted to account for **30%** of solar cell capacity, and

till y. 2015 for as much as 50%!

Thin Film Solar Cells

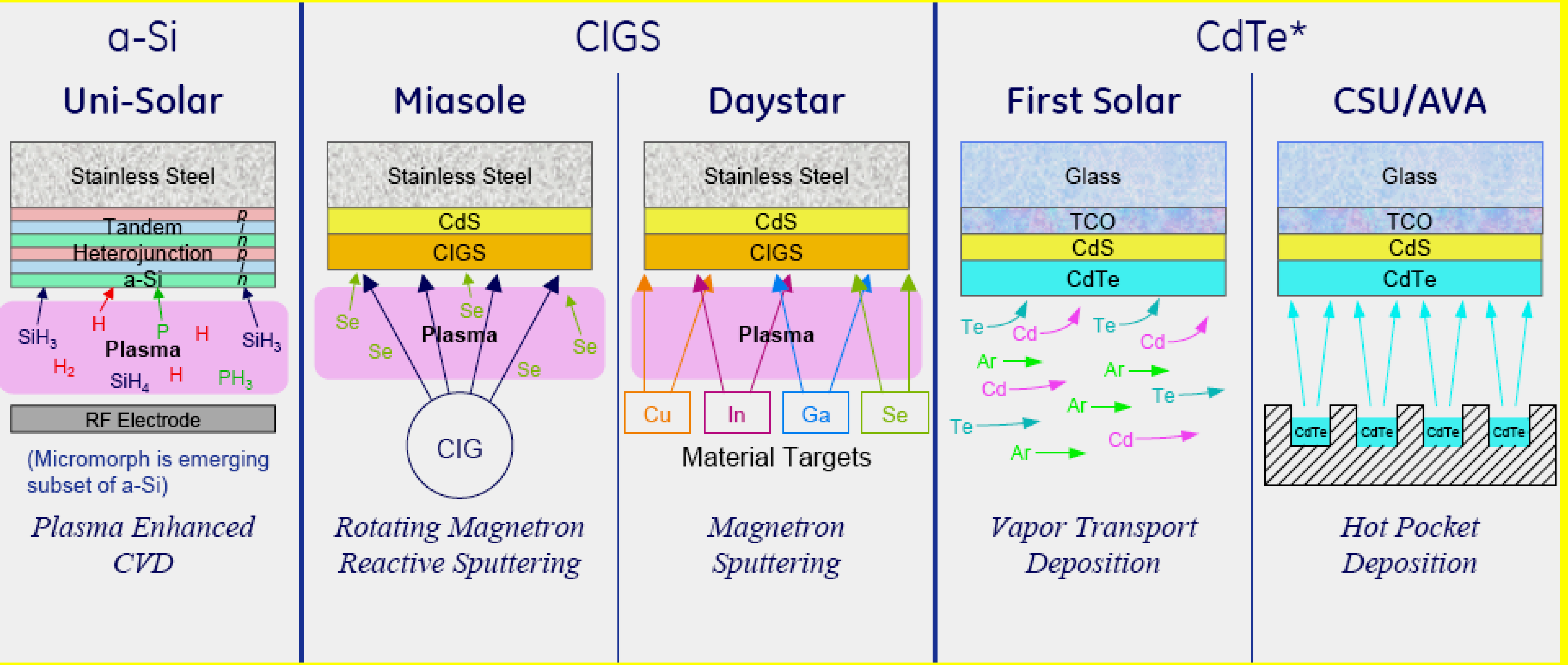
The main advantages of thin film solar cells:

- Much less material needed
-Usually much simpler technologies
-usually much less energy needed in production

The main disadvantages:

-Material is still far less perfect than c-Si
-Lower efficiency
-Shorter or not yet proved long lifetime of most thin solar cells

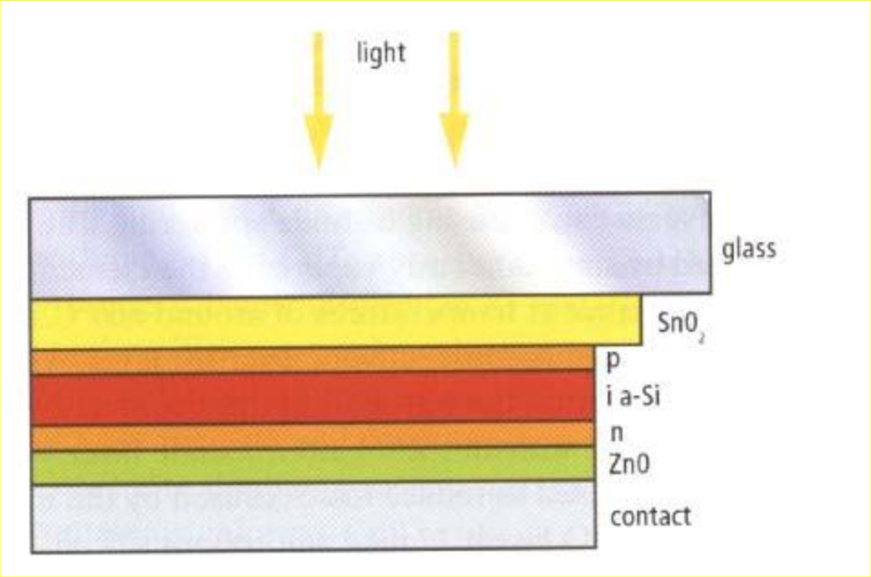
Thin film technologies

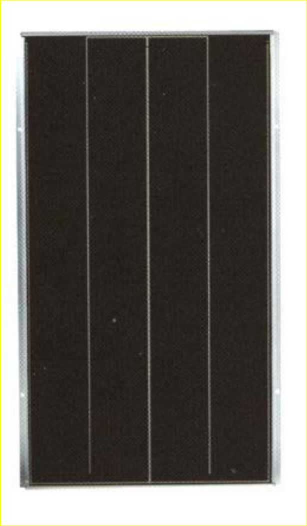


Leading Thin film materials for solar cells (at present):

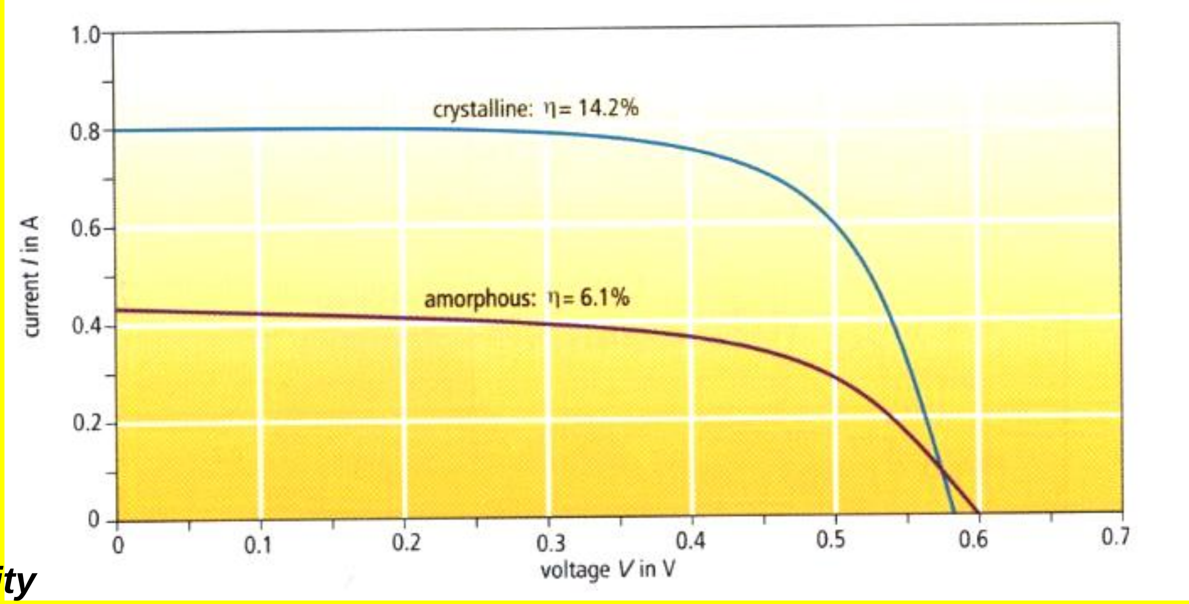
Amorphous silicon **(a-Si),** Copper Indium di-Selenide **(CIS**), Copper Indium Galium Sulphide **(CIGS),** cadmium telluride (**CdTe**), thin-film silicon Si (as¸micro- or nanocrystalline Si, **mc-Si, nc-Si**) – all polycrstalline, and Gallium Arsenide **(GaAs)** **(**monocrystalline**,** high-efficiency thin film)

Amorphous Si (a-Si) module





Amorphous Si vs. Crystalline Si module



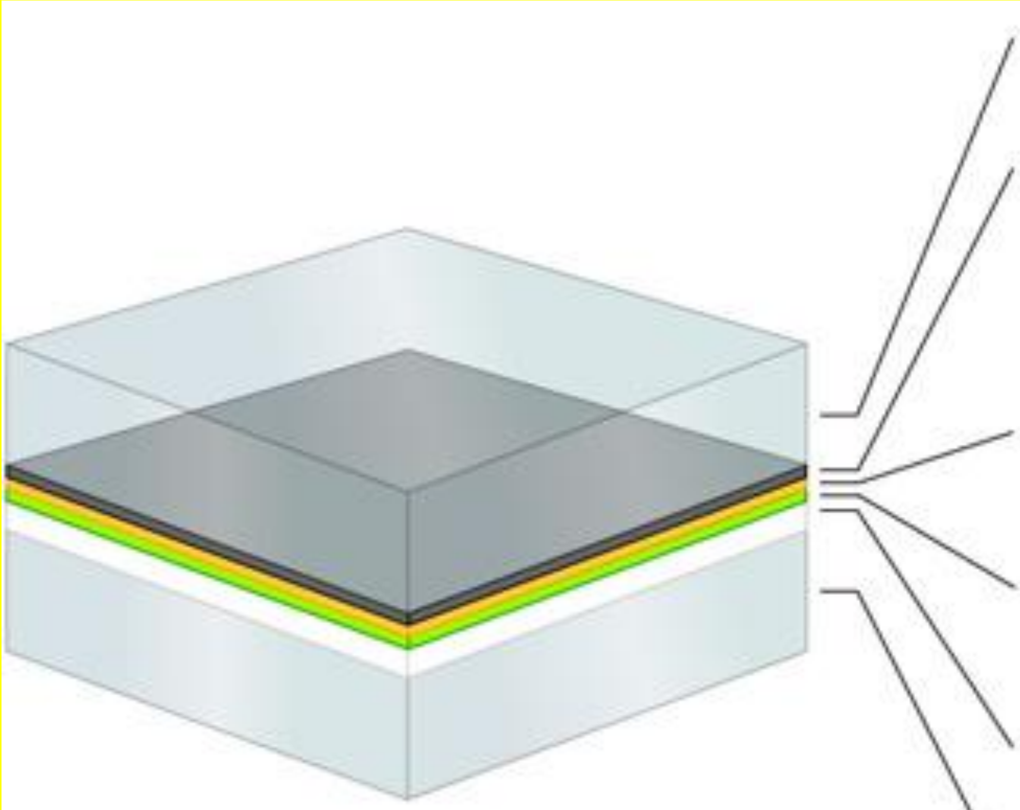
Amorphous Si thin film device structure:

- P-i-N ('pin') diode consists of three separate thin a-Si films

-a thin conductive oxide on the glass serves as a window

-a-Si is long time at the market, the efficiency is still relatively low; inherent problems with solar cell stability

CdTe Solar PV Cells (manufacturer: *First Solar*)



The First Solar module is comprised of two semiconductor materials:
CdTe (p-type) and CdS (n-type, also window layer). Cd and Te are sourced as byproducts of mining operations.

Best efficiency, acheaved in the Lab till now is 16 % (12-14 % in mass production).

Success story of *First Solar*
(producer of thin-film CdTe solar cells)

-Founded **1999**

-A stunning **795% growth** in **2007**,

Revenues more than tripled, **profits** rose **about ten times**

Company's stock has gone from **$20 to over $200/share in just one year**.

- In **2008** First Solar rose to the 4th largest manufacturer of solar cells in the word

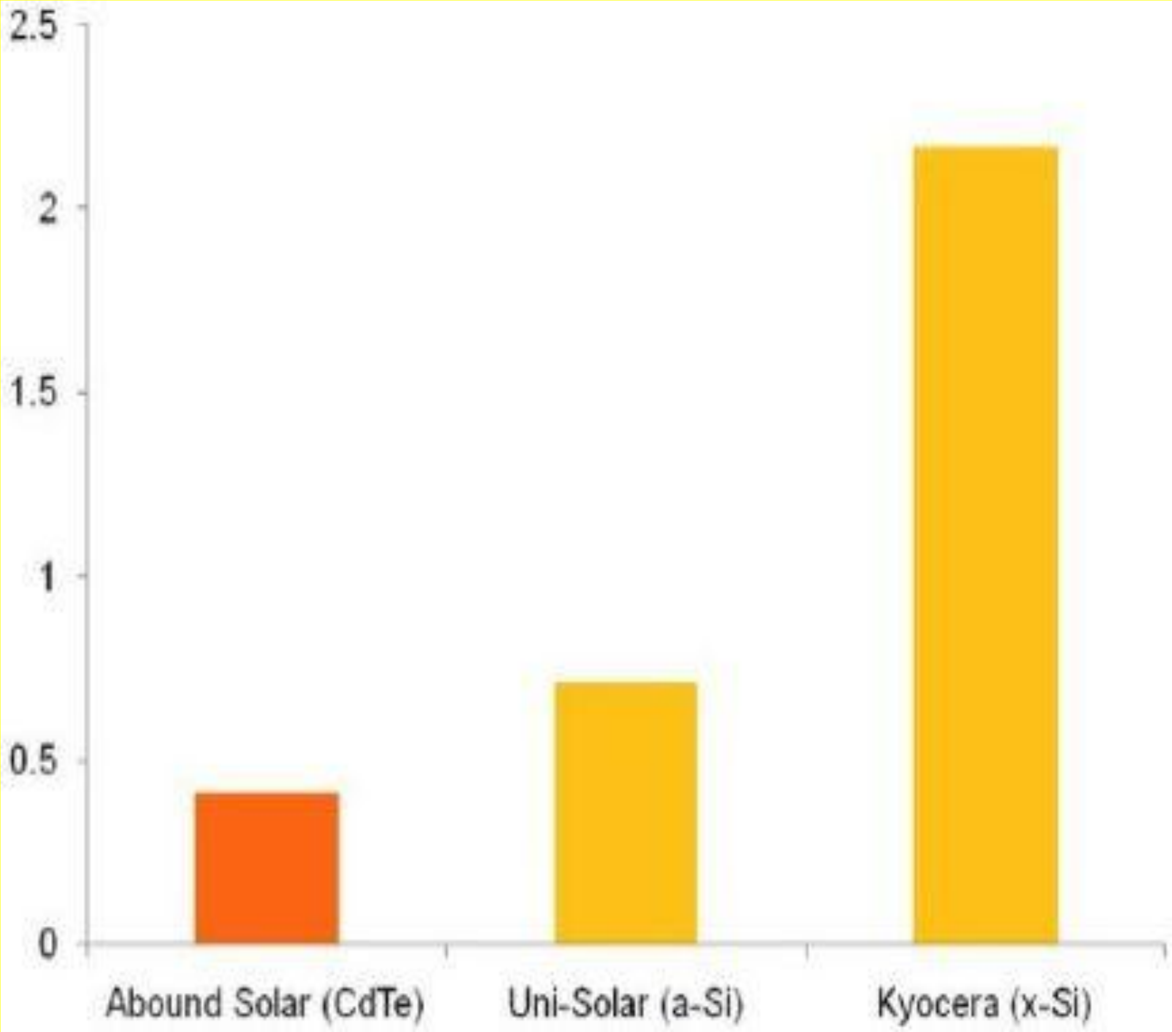
- In **2009,** *with over* 1000 megawatts of annual capacity, *First Solar* become the largest manufacturer of solar cells in the world!

Strong scientific support:
Researchers at both **Lawrence Berkeley Lab** and the **National Renewable Energy Lab** are working, among others, on cadmium-telluride cells.

First Solar says its **manufacturing cost was $\$0.76/W_p$ as of Q'02 2010**, and the average **large-scale efficiency** of its panels is around **12 %.**

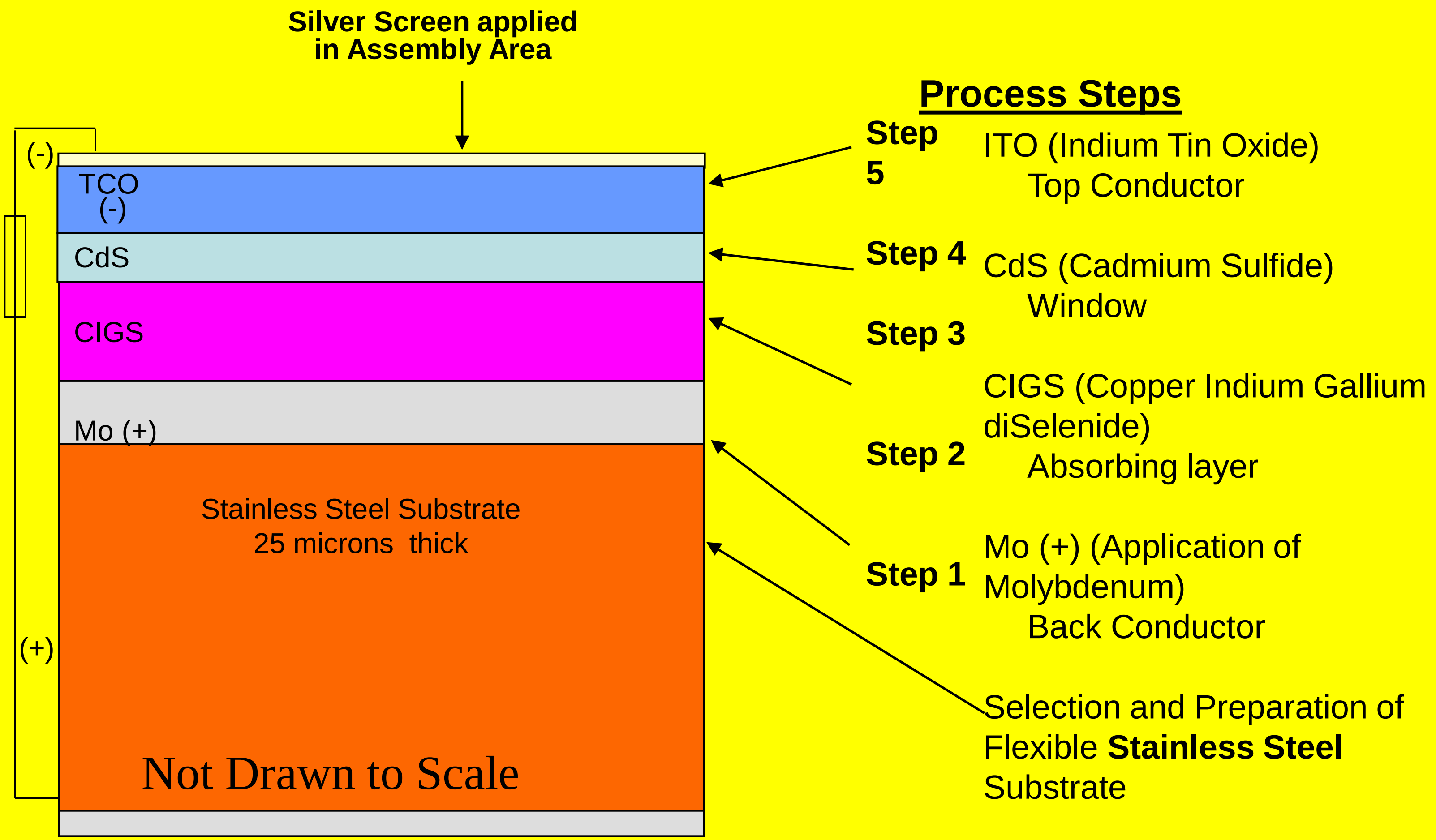
For comparison:
Germany's producer ***Q-Cells*** is building production line of CdTe, but it will become operational at the end of 2010, and the plant will have 'only' a **25 MW_p/year** capacity.

Besides relative simplicity of manufacturing, the process is also energy favourable:



Energy payback time (in years) of CdTe, c-Si and a-Si modules.
*(**Source:** Bousted Consulting Environmental Report)*

CIGS (Copper Indium Gallium Sulphide) thin-film solar cells



(Flexible substrate: Very thin Stainless Steel)

Flexible ,very thin substrate offers great flexibility in applications

CIGS thin-film solar cells

In 2009, CIGS companies worldwide collectively shipped only about 43 MW_p of solar panels, still …..
….. CIGS will most likely be the next thin-film photovoltaic technology to take-off after CdTe!

.

Some reasons:

- Best efficiency, achieved in the Lab till now, is 20,1%

obtained in 2010 by Centre for Solar Energy and Hydrogen Research (ZSW), Ge (Process was a modified co-evaporation process, which ,“... can be scaled up to a commercial production process” with 15% efficiency.
(Other Lab “records”: 20,0% – *NREL* Lab and 19,9% in *Nanosolar* Lab), Commercially available CIGS modules have now 10%-12% efficiency).

CIGS thin-film solar cells - year 2010

Great expectations from CIGS:

In 2010 a number of companies were confident enough in their CIGS technological solutions to build **large-scale CIGS solar cells factories**:

Stion (USA) just raised $70 million to expand the annual capacity of its CIGS factory from 10 MW to **100 MW_p**.
Solyndra (USA) is building a factory (loan $535 millions and $175 million from existing investors) to be able to increase the annual production to **300 MW_p** by the end of 2011**.**
Sulfurcell, (Germany) maker of copper-indium-sulfide (CIS) panels and is backed by Intel Capital, built a **75-MW_p** factory last year in Berlin. Suolfucell started production in 2005 with around 8% efficiency. Sulfurcell expects to boost the efficiency to at least 10% by 2011. The goal is to get to 15% by 2015
Solar Frontier *(Japan)* succeeded to rise $1 billion investment to build the **900-MW_p plant**, to complement its current a 20-MW and a 60-MW CIGS plants. By adding the third factory, *Solar Frontier* is poised to be the second largest thin-film manufacturer, with **980 MW_p total annual capacity**.
Solar Frontier is currently producing panels with **11.5% average efficiency**, and it expects to increase it to **14% by 2014**.

Is there limits for thin film solar cells?

Are there limits to the PV growth ?

Material constrains for leading thin-films solar cells

Table 1. Materials requirements and indicators for the solar cells in four solar energy systems, each based on a specific thin-film technology supplying 100,000 TWh/yr.

	Materials requirements (g/m^2)	Total material requirements[b] (Gg)	Total material requirements /reserves[c]	Total material requirements /max. resources[d]	Annual material requirements[e] /refined materials[f]	Potential losses[g]/ weathered amounts[h]	Material cost share[i] (%)
a-SiGe[a]							
Sn	3.3	1700	0.20	0.004	0.079	2	0.04
Ge	0.22	110	51	0.0003	21	0.1	0.5
Si	0.54	270	Negligible	Negligible	0.0031	0.000002	0.002
Al	2.7	1400	0.00032	Negligible	0.00075	0.00005	0.008
CdTe							
Sn	0.66	330	0.056	0.0009	0.016	0.4	0.008
Cd	4.9	2400	4.6	0.03–0.1	1.2	10–50	0.02
Te	4.7	2400	110	1–20	120	500–10 000	0.5
Mo	10	5100	0.93	0.01	0.47	6	0.1
CIGS							
Zn	9.1	4600	0.030	0.0003	0.0062	0.1	0.02
Cu	1.8	880	0.0017	0.00009	0.00098	0.04	0.008
In	2.9	1400	650	0.03–0.4	110	10–200	0.8
Ga	0.53	270	25	0.00007	48	0.03	0.4
Se	4.8	2400	30	0.3	12	100	0.1
Cd	0.19	95	0.18	0.001–0.005	0.048	0.4–2	0.0008
Mo	10	5100	0.93	0.01	0.47	6	0.1

From: Anderson B.A. et. all, Chalmers University

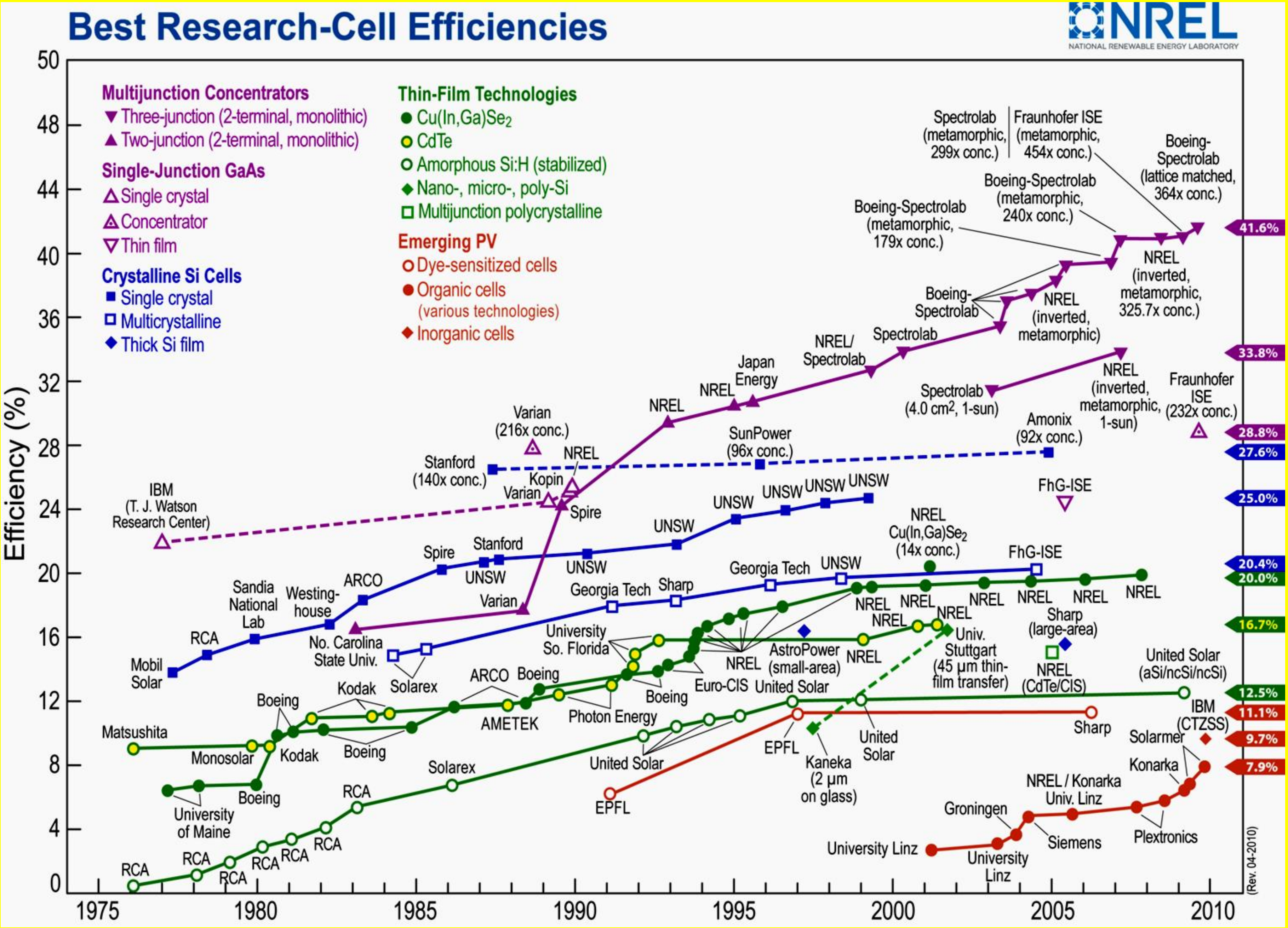
Few New concepts or New technological solutions in Solar cells

(not yet on the (large-scale) market)

PV is an extremely dinamic field, with a lot of room for improvements or for completely new ideas.

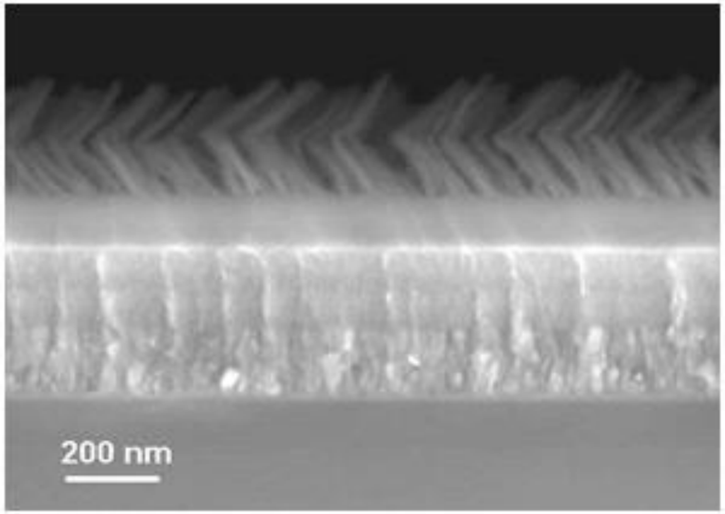
Here is my personal choice among a large number of **prospective new PV aproaches or technologies**

a) The increase of Solar cell/module efficiency

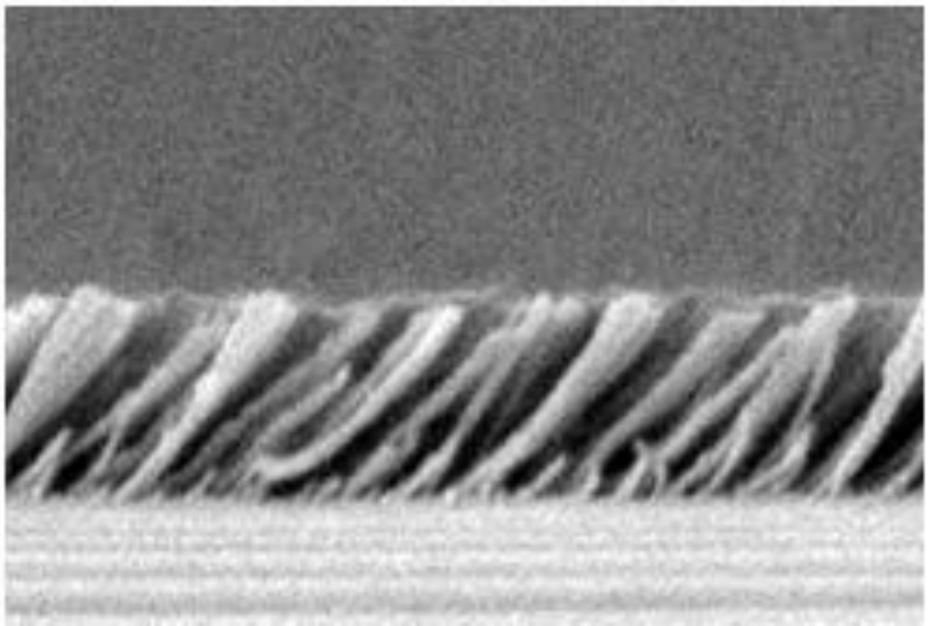


a) Technological improvement with potential benefit to all types of cells

Solar Power Game-Changer: Near Perfect Absorption of Sunlight, From All Angles 2009

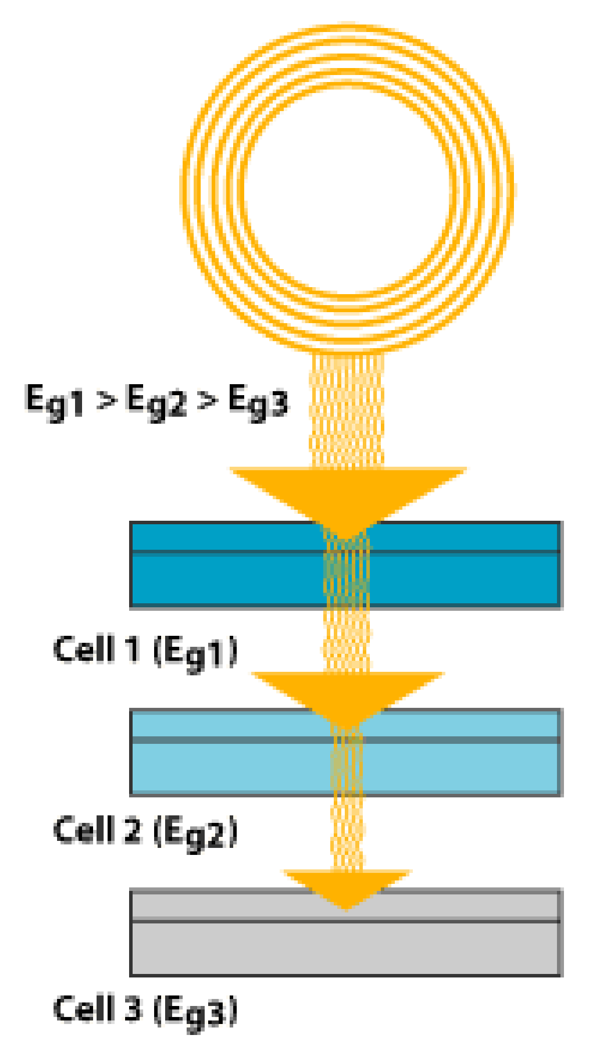


Recently Rensselaer Polytechnic Institute announced new antireflecing coating, which, affixed to solar cell surface capture about **97%** of incoming sunlight.



:*Coating is made of silicon dioxide and titanium dioxide **nanorods** positioned at an oblique angle — layer looks and functions **similar to a dense forest where sunlight is "captured" between the trees**. The nanorods were attached to a **silicon substrate** via chemical vapor disposition. T**he new coating can be affixed to nearly any photovoltaic materials** for use in solar cells, including III-V multi-junction and CdTe"*

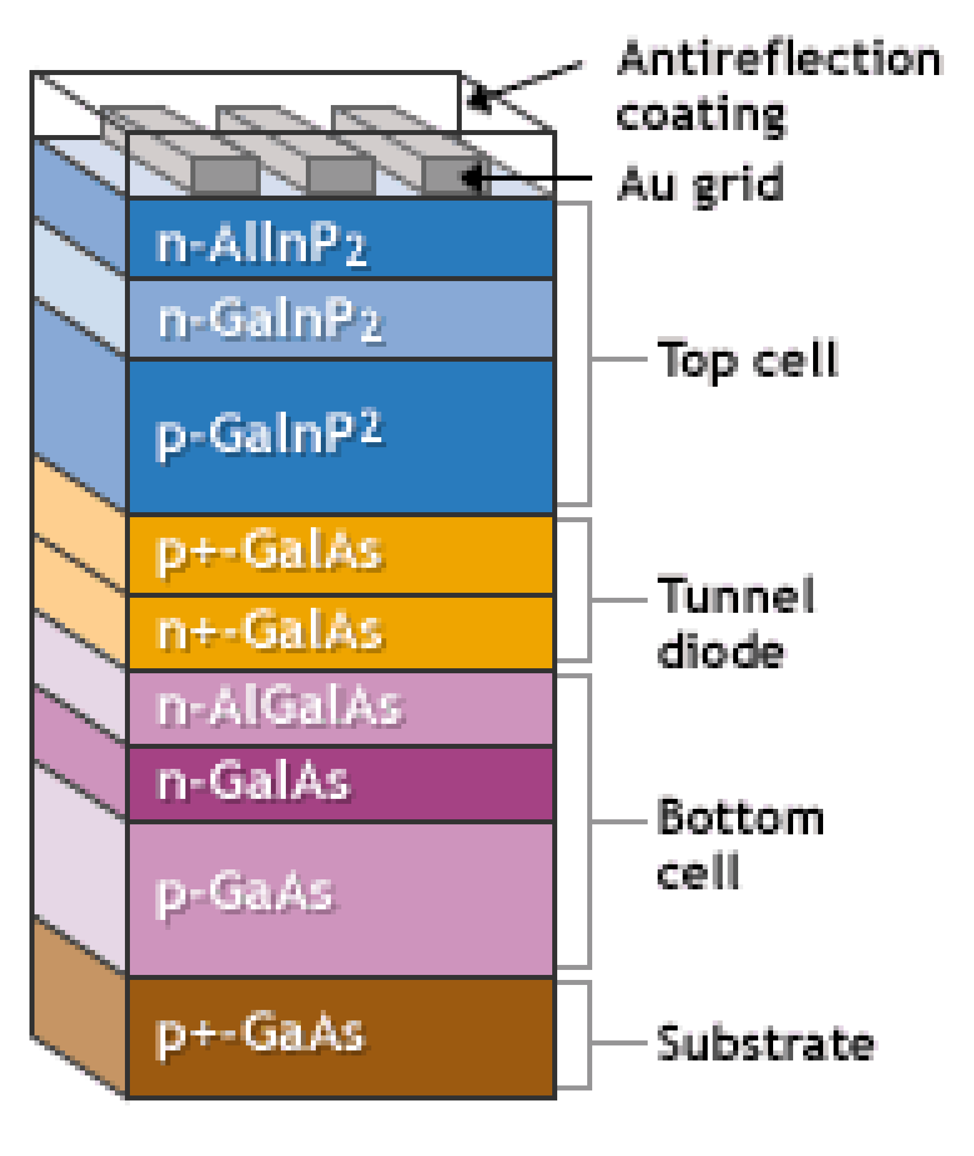
Multi-junction Devices



This structure, also called a **cascade or tandem cell,** can achieve a **higher total conversion efficiency by capturing a larger portion of the solar spectrum**.

A multijunction device is a stack of individual single-junction cells in descending order of bandgap (Eg).
The top cell captures the high-energy photons and passes the rest of the photons on to be absorbed by lower-bandgap cells.

Multijunction Devices

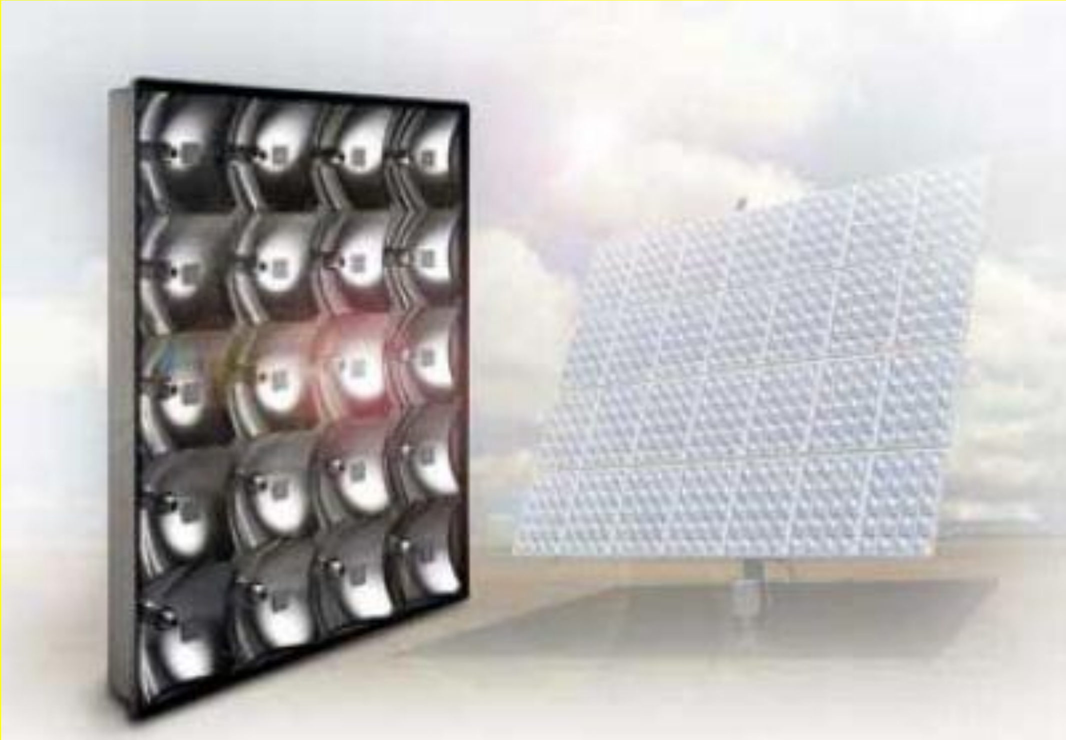


This multijunction (monolithic) device with **gallium arsenide as a basis.**

These cells have **efficiencies of up to 42%,** and more than **35% under concentrated sunlight**

Other materials studied for multijunction devices are a-Si, CIS and CdTe.

Concentrator photovoltaics



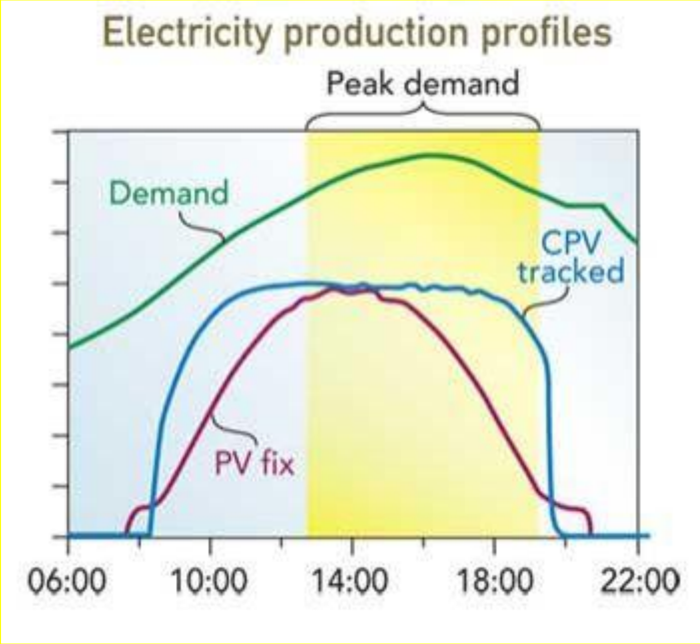
The SolFocus very high-efficiency SF-1100 arrays are comprised of 28 300W panels mounted on a dual axis tracker. Energy output is maximized throughout the day.

From a scalability standpoint:

CPV systems use much less specialized PV material. The majority of the system is built from “simple” materials -**aluminum or glass** that can be sourced globally.

Concentrator photovoltaics & development of trackers

Several of the first market-ready CPV products have been installed in power plants in 2008 and 2009; the technology is now ready for the next wave, with multi megawatts (MW) to be installed in 2010



Tracker technologies improve grossly in last few years: *Solar trackers in Richmond, CA*

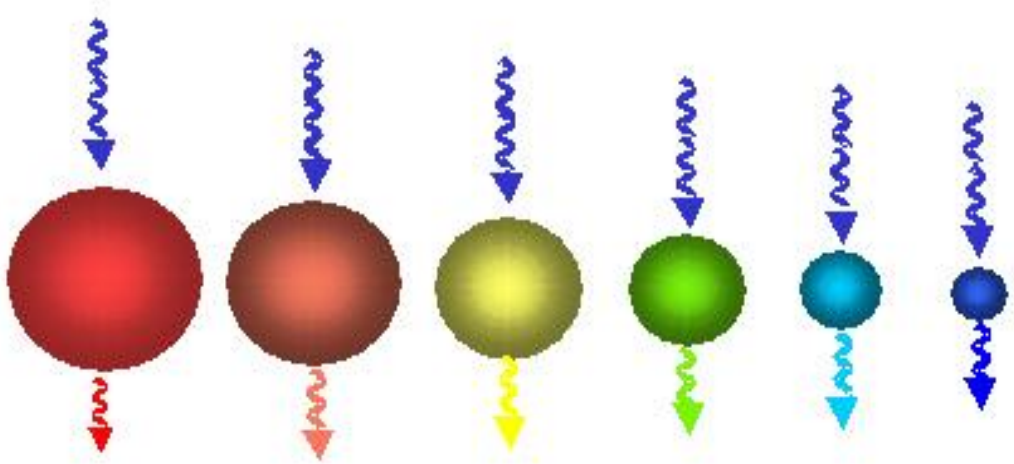
PV Power plants

World's largest photovoltaic (PV) power plants (40 MW or larger)					
Name of PV power plant	**Country**	**Nominal Power (MW_p)**	**GW·h /year**	**Capacity factor**	**Notes**
Olmedilla Photovoltaic Park	Spain	55	85	0.16	c-Si modules. Completed Sept. 2008
Strasskirchen Solar Park	Germany	54			
Lieberose Photovoltaic Park	Germany	53	53	0.11	700,000 First Solar CdTe modules, opened 2009
Puertollano Photovoltaic Park	Spain	47.6			231,653 c-Si modules, Suntech/Solaria, opnd 2008
Moura photovoltaic power station	Portugal	46	93	0.23	Completed December 2008
Kothen Solar Park	Germany	45			2009
Finsterwalde Solar Park	Germany	41			2009
Waldpolenz Solar Park	Germany	40	40]	0.11	550,000 First Solar thin-film CdTe modules.Compl. Dec 2008

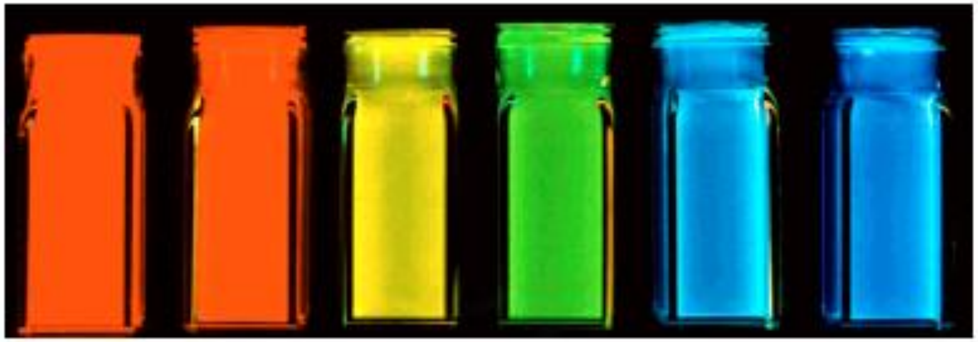
Topaz Solar Farm is a **550 MW_p** solar PV power plant, to be built northwest of California Valley in the USA at a cost of over $1 billion. Built on 25 km^2 of ranchland, the project would utilize thin-film PV panels designed/manufactured by OptiSolar in Hayward and Sacramento. The project would deliver approximately 1,100 GWh annually. The project is expected to begin construction in 2010,_begin power delivery in 2011, and be fully operational by 2013.

“Nanocrystalls” or “Quantum Dots”

– their size determine their band-gap and, hence, the size effectively determines which part of solar spectra is absorbed



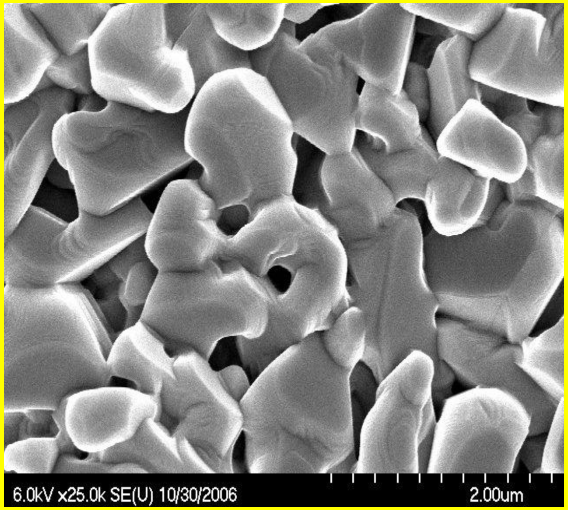
The size of nanocrystals, at nanometer scale determines the bandgap, (and hence color) and then which part of solar spectrum is absorbed

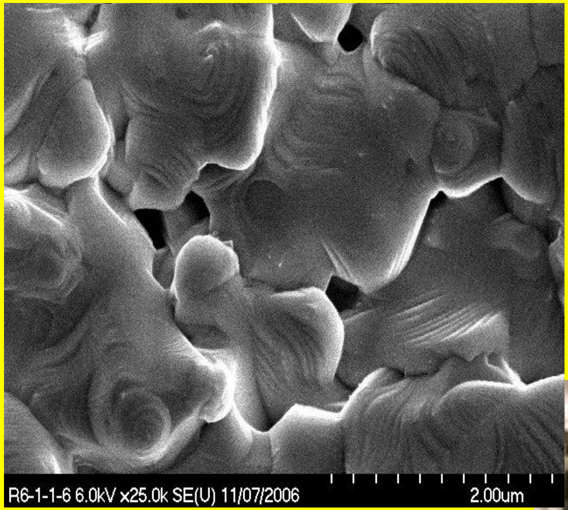


Six solutions with nanocrystals of the same semiconductor (CdS), but CdS nancrystals are of different size in each container

Solar Cells using printing of nanoparticles

From *Nanosolar* (U.S.A.):
*H*igh-throughput, high-yield processing in the form of **(non-vacuum) printing of** $Cu_{In}xGa_{1-x}Se_2$ **(CIGS) nanoparticles from ink solution** onto low-cost substrates (metal foil or glass)
Converting these layers into high-quality electronic films using rapid thermal processing (RTP) techniques.



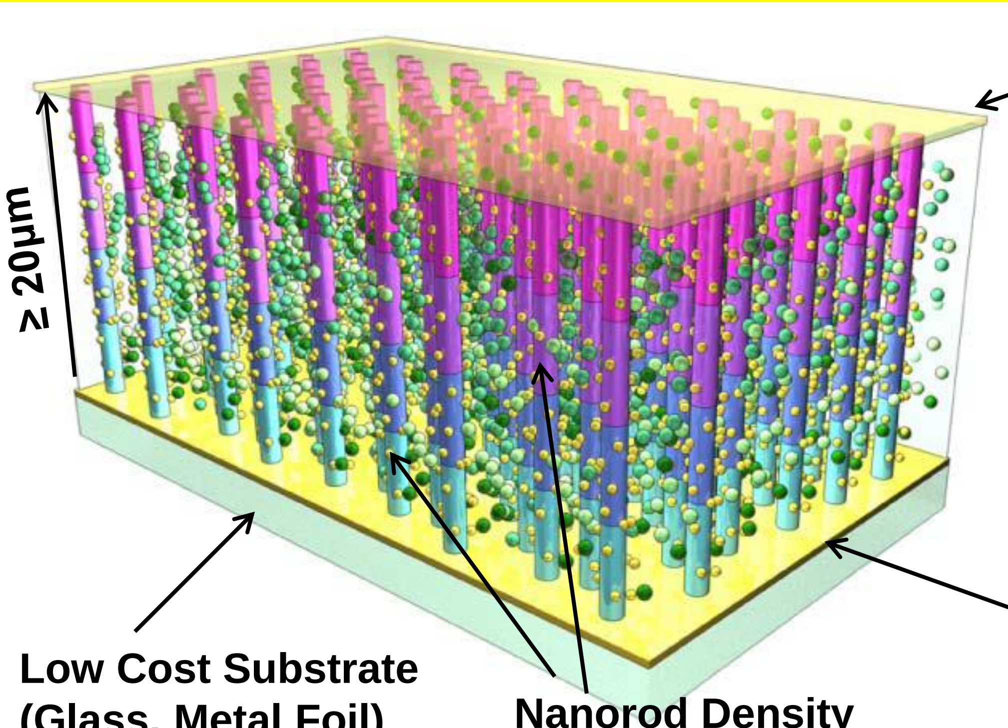


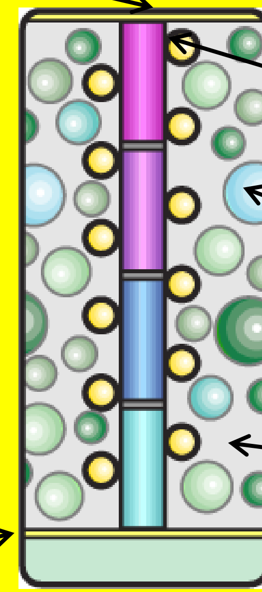
SEM images of **CIGS film** on glass (left) and on foil (right).

Solar **cell efficiencies: 14%**
(have been confirmed by *NREL*)
Product cost: *Nanosolar* claims to have produced "cell costs [of] only \$0.36 Wp," and an
"aim to produce the panels for \$0.99 W_p
Production line: one solar panel every ten seconds on each line of production

Nanostructured Solar Cells

Top,Transparent, Contact





Metal Nanoparticles

Quantum-Splitting Phosphors

Dielectric Films (SiOx, Si-N, Polymer, etc.)

Low Cost Substrate (Glass, Metal Foil)

Nanorod Density $\geq 10^{12}/cm^2$

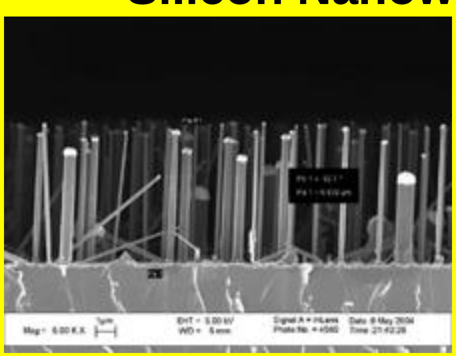
Bottom Contact

Multi-Bandgap Nanowire

Advantages

- Low (insignificant) material cost
- Multiple bandgaps for UV/IR absorption
- High mobility and lifetime
- Multiple absorption mechanisms
- Integration with low cost substrates
- Roll-to-roll manufacturing

Silicon Nanowire Project



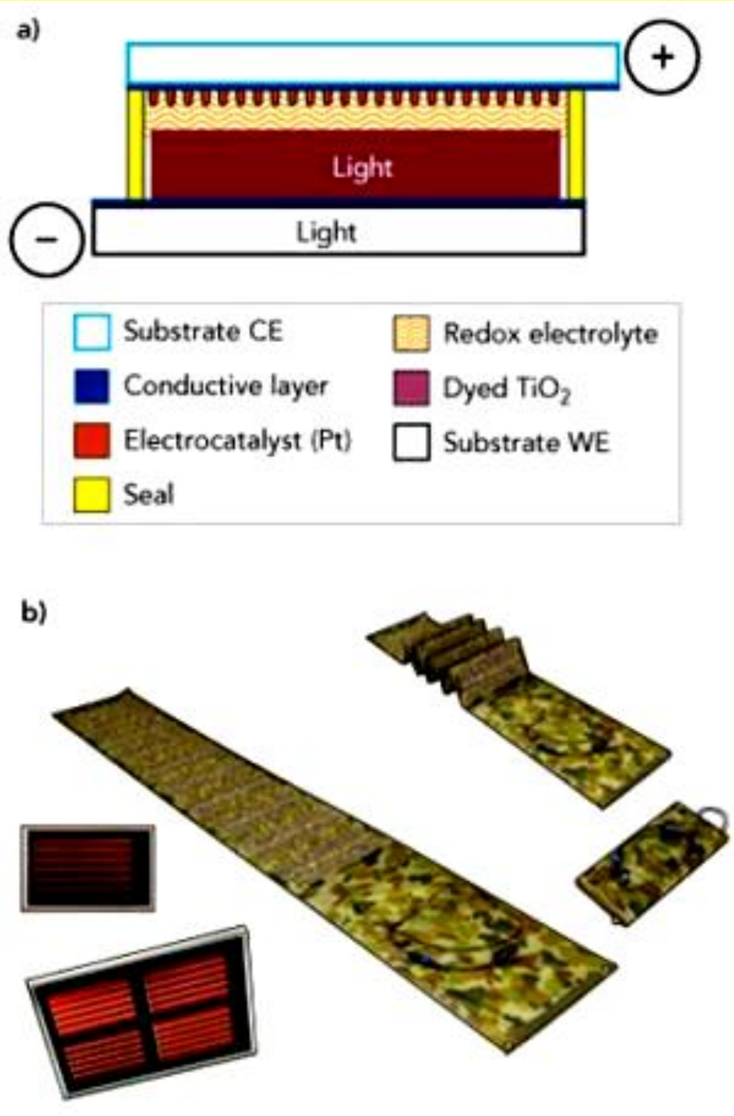
Si nanowires grown by low cost CVD techniques

Goal is 20% efficiency at thin film material cost

Dye solar cells

DSC – marriage between nanotechnology and photosynthesis

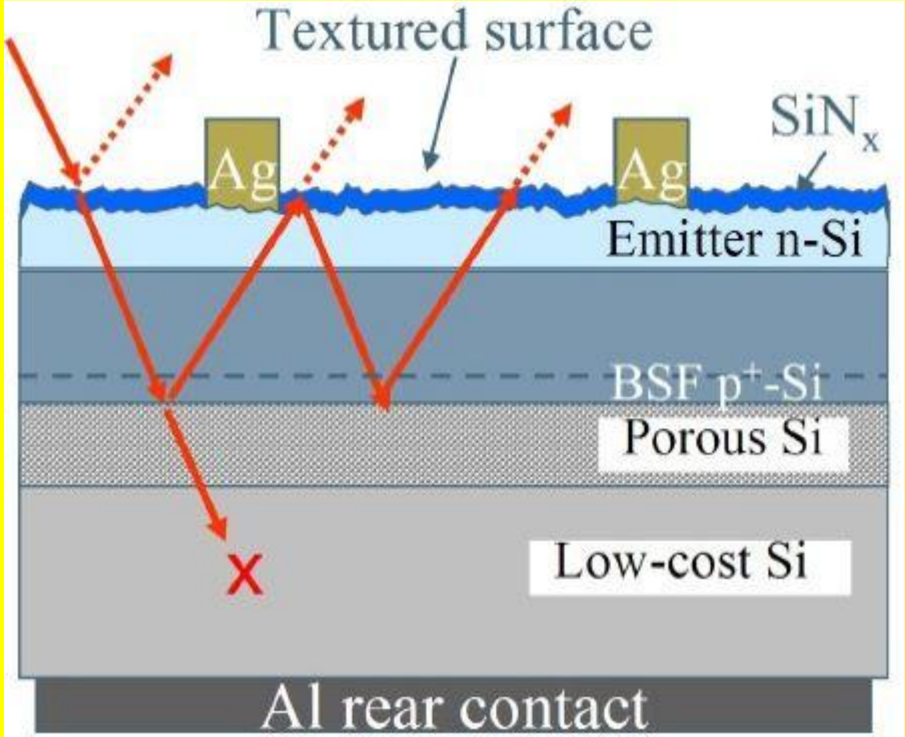
Dye solar cells are based on nanomaterials: light harvesting and transformation through photochemical and charge transfer reactions show many analogies to photosynthesis.
A DSC consists of two electrodes. The first working electrode (WE) substrate (e.g., conductive glass, plastic or foil) is coated with a thin (<20micron) film of nanoparticulate titanium dioxide (TiO_2).
A very small amount of photoactive dye (a single molecular layer only) such as a ruthenium-based compound is adsorbed to the TiO_2 surface. The two electrodes are separated by a sealant gasket and a redox electrolyte layer. The second cell electrode referred to as the counter electrode (CE) consists of a conductive substrate that is coated with a thin layer of a transparent catalyst



a) Schematic diagram of typical glass and/or flexible DSC highlighting the key cell components; and
b) various photographs of typical Dyesol glass and flexible DSC devices in various configurations and arrangements

Very thin Si solar cells:

Based on the roadmap for thin c-Si solar cells in future IC technologies&methodologies.



Only a thin (<20µm) high-quality Si active layer would be needed if good reflectors could be built around it.

Porous Si reflector (Back Surface Field) is one of the candidates

n the lab, efficiencies of **16.1%** was acheaved

PV market development in 21st century

PV market growth, module installation and price rates

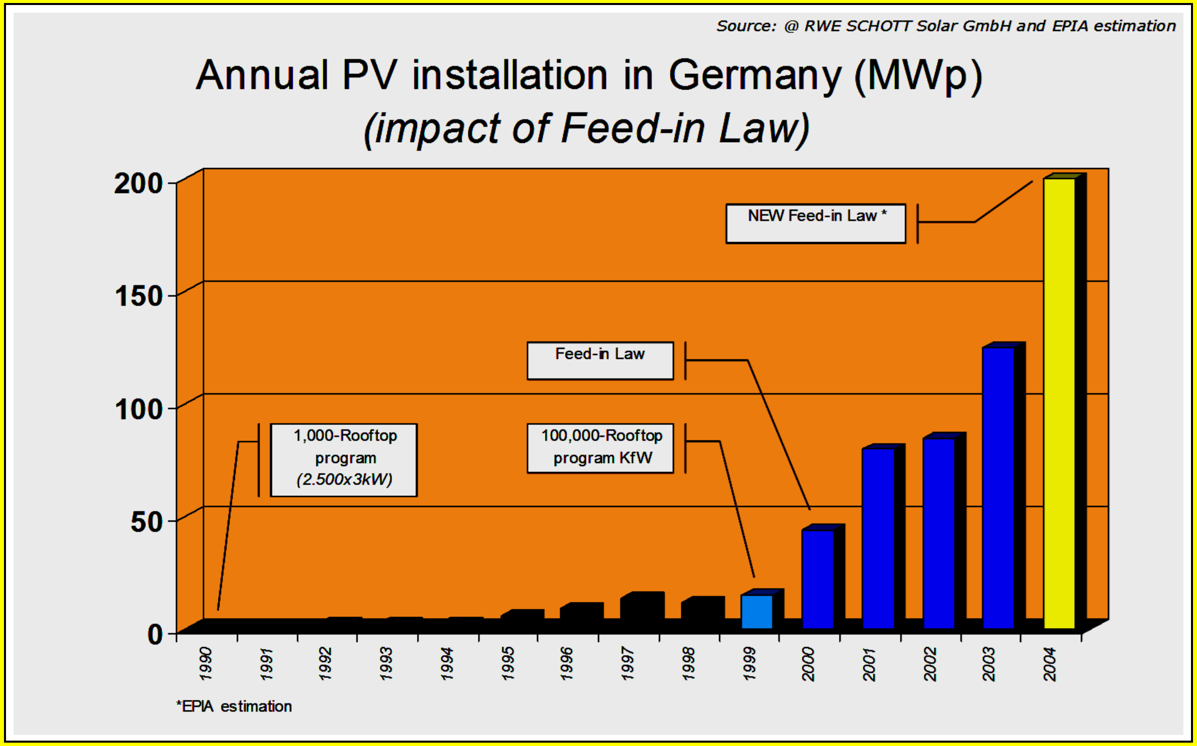
Years 1999-2008 - a fantastic decade
in which PV incresed 14 times, up to 4.5 GW in 2008

Growth was fueled

- by strong policies and generous subsidies

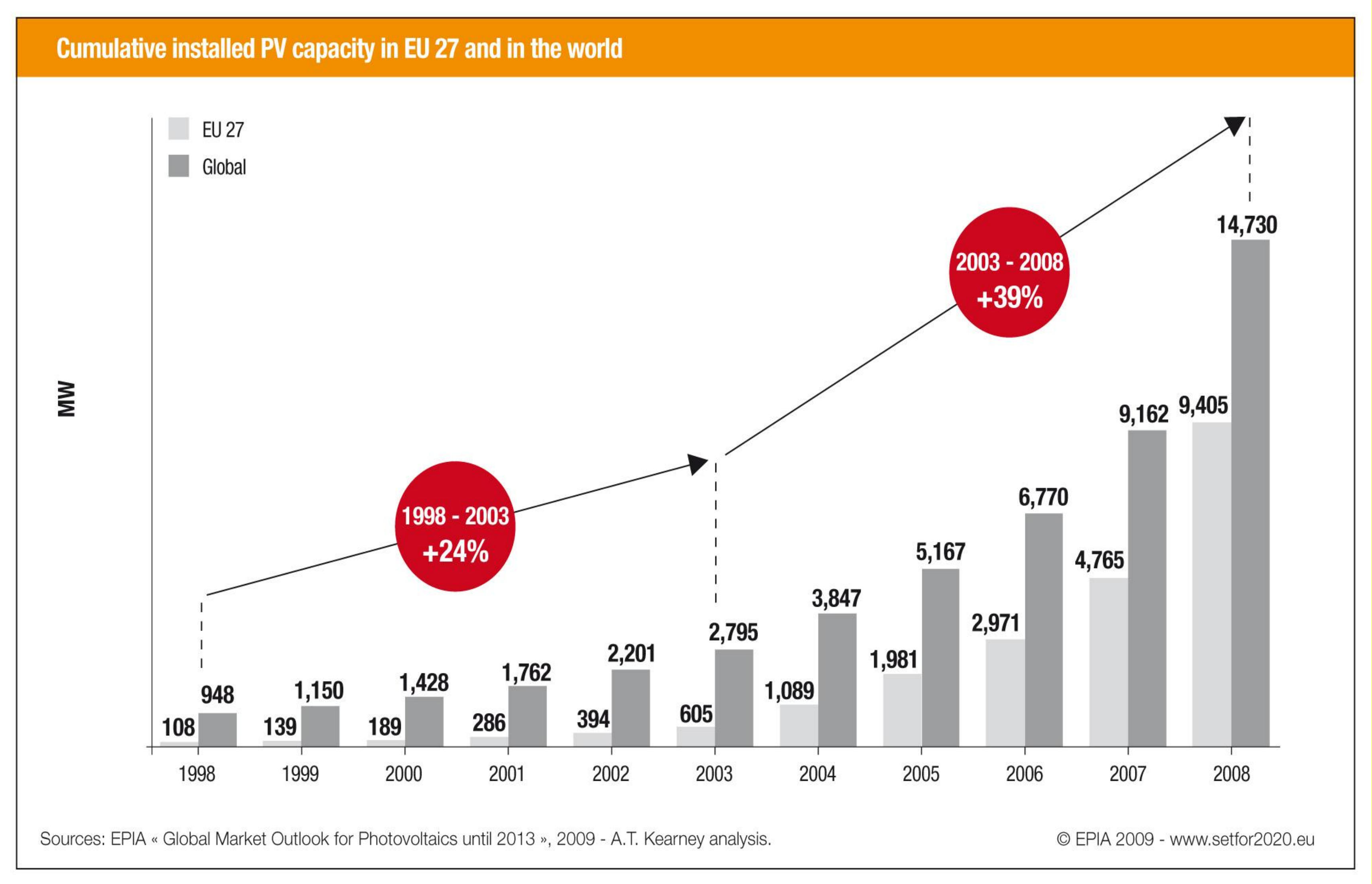
- by increased awareness of pollution and climatic changes threath,

- by instabilities of energy supply (strong dependence on oil import)



Example of Germany: how particular measure(s) in early days had stimulated PV growth

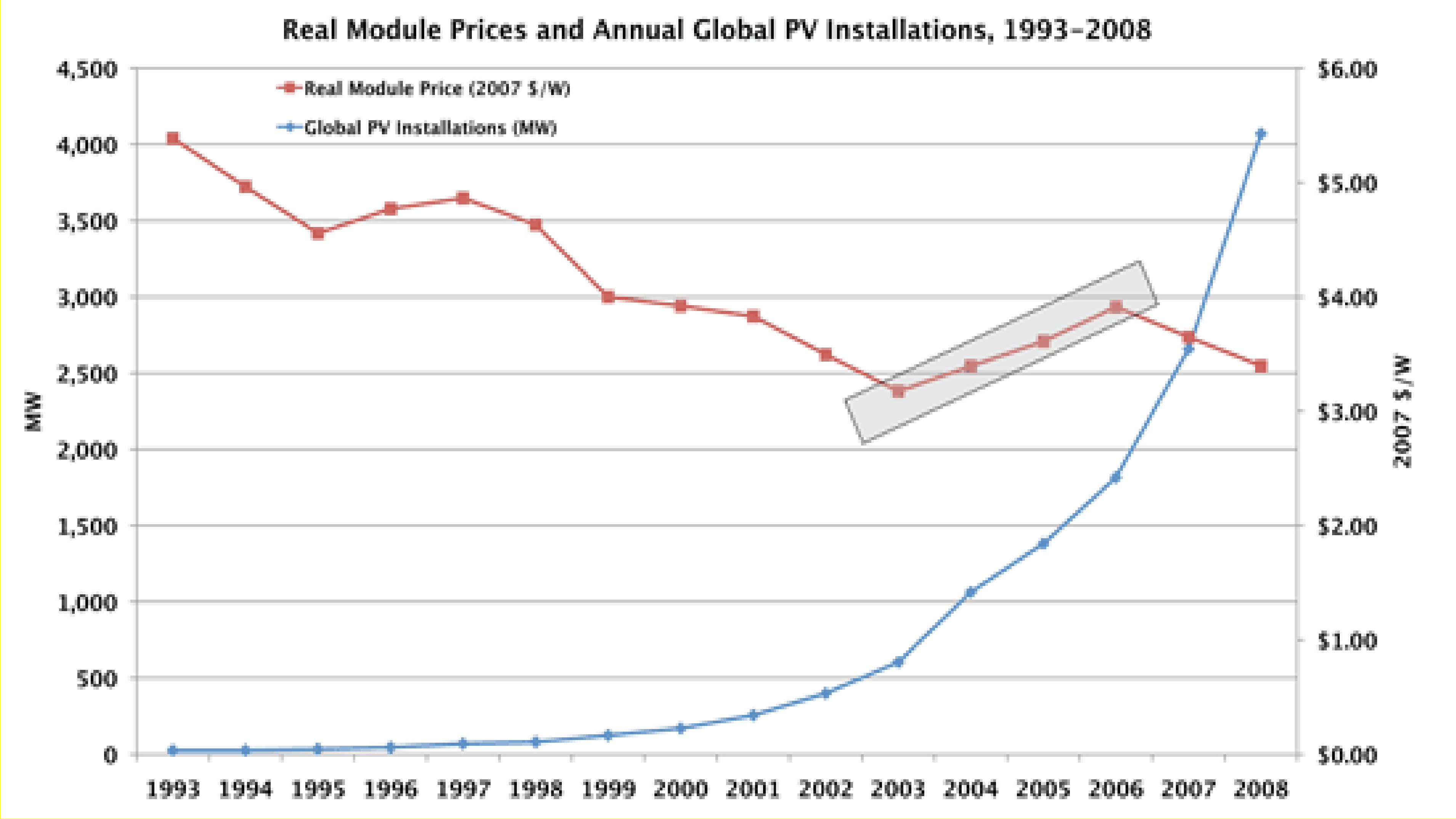
10 Years in the Sun: The Best Decade in PV History



Growth accelerated from doubling PV production capacity (roughly) every 3 years to **doubling capacity faster than in every. 2 years**

If trend¸would continue – a 10^3 increase would happen in less than 20 years!

PV Cells – Modules prices,



Source *:*Prometheus Institute: *PV Technology, Production and Cost, 2009:* Real module prices and Global PV Installations,, 1983-2008.

PV become a (temporary) victim of its own enormous success!!

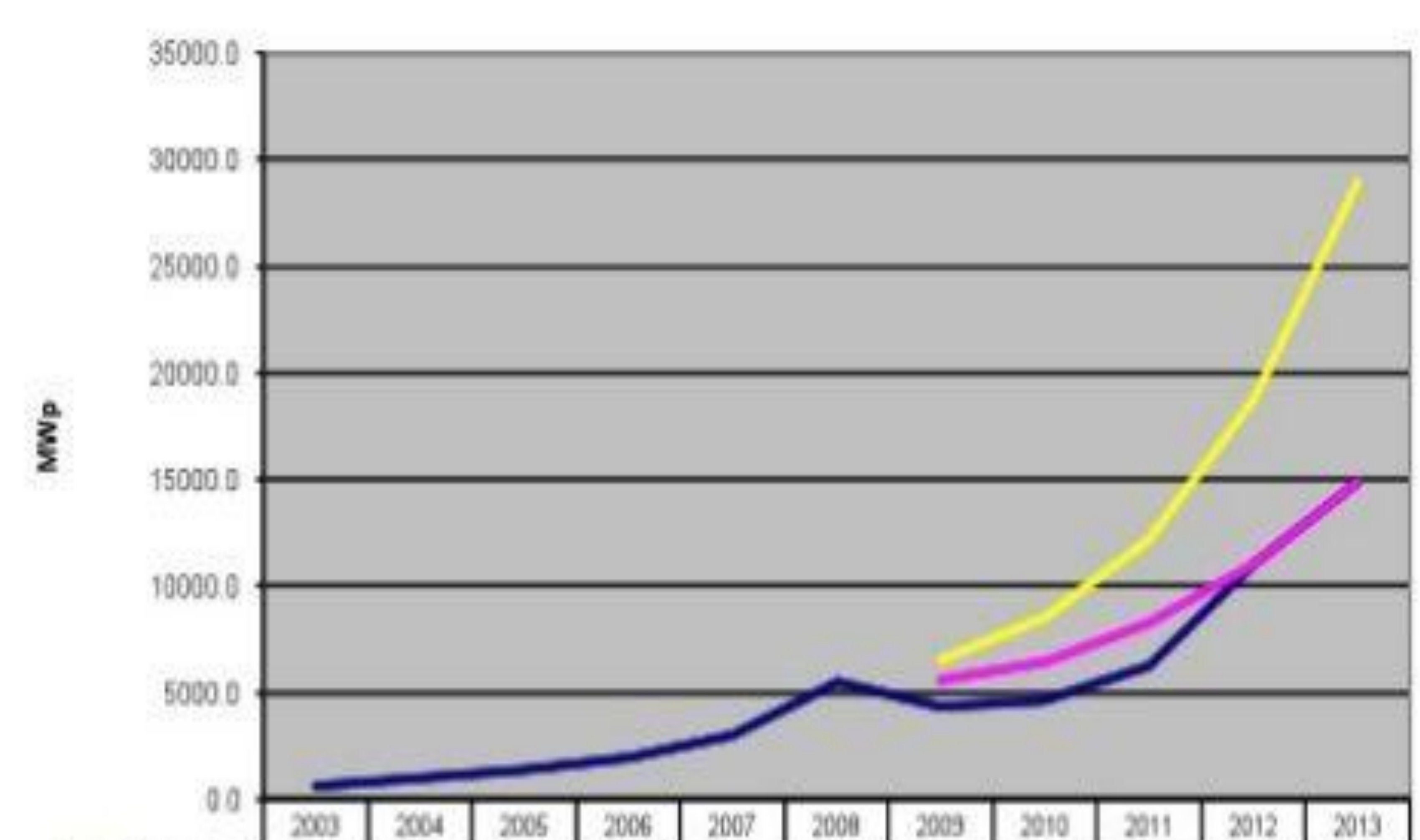
Year 2009:

- **Year of economic world crisis**

- **A lot of perturbations and turmoil also in PV industry**

-**.....a year that tested the vitality of the field**

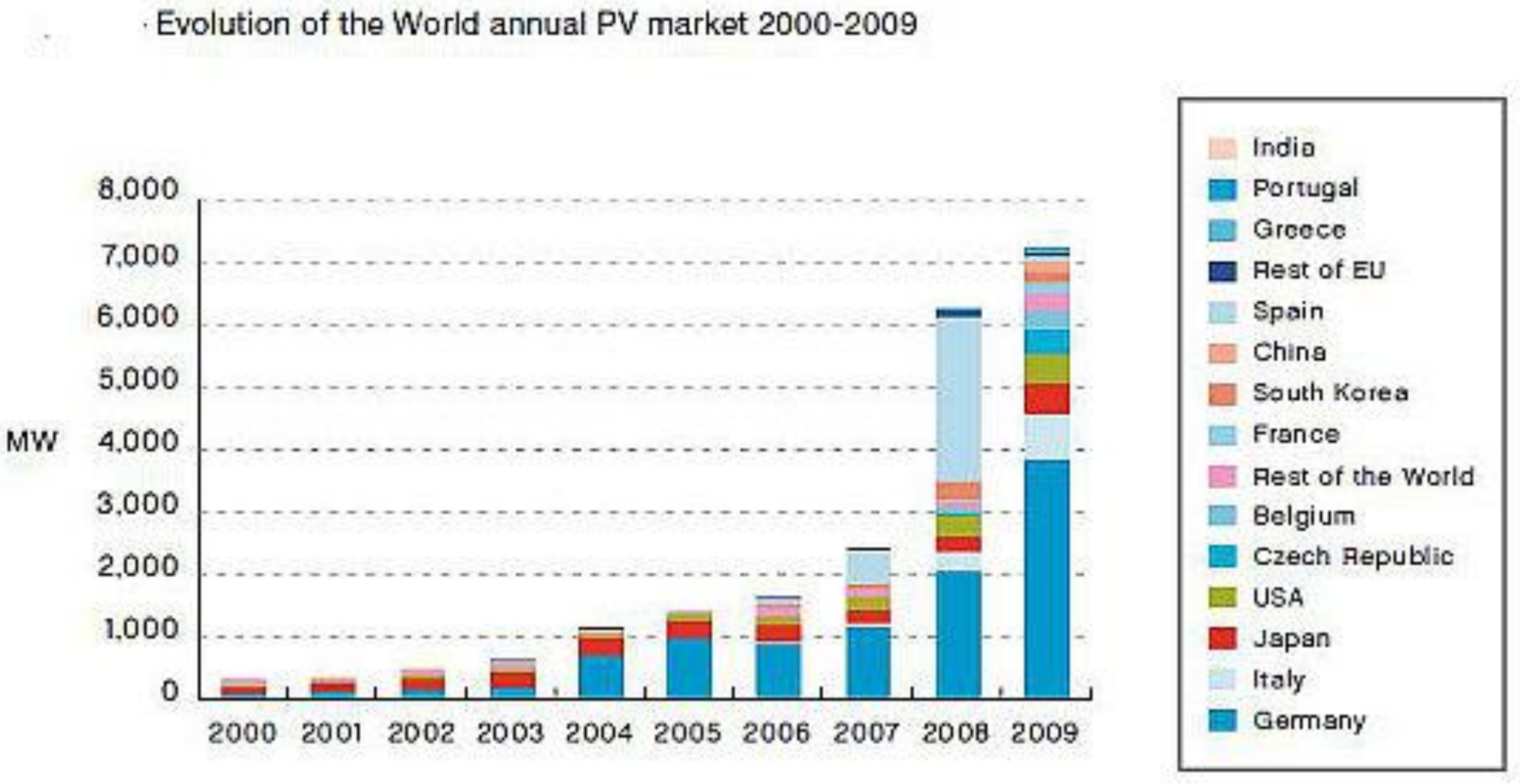
Forecast for PV was a very difficult task, even for professionals:



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Recession	675.4	1049.8	1407.7	1984.6	3073.0	5491.8	4373.4	4710.7	6248.6	11079.7	14852.1
Conservative							5618.2	6436.4	8286.0	11079.7	14852.1
Accelerated							6538.8	8564.3	12283.7	18846.5	28994.4

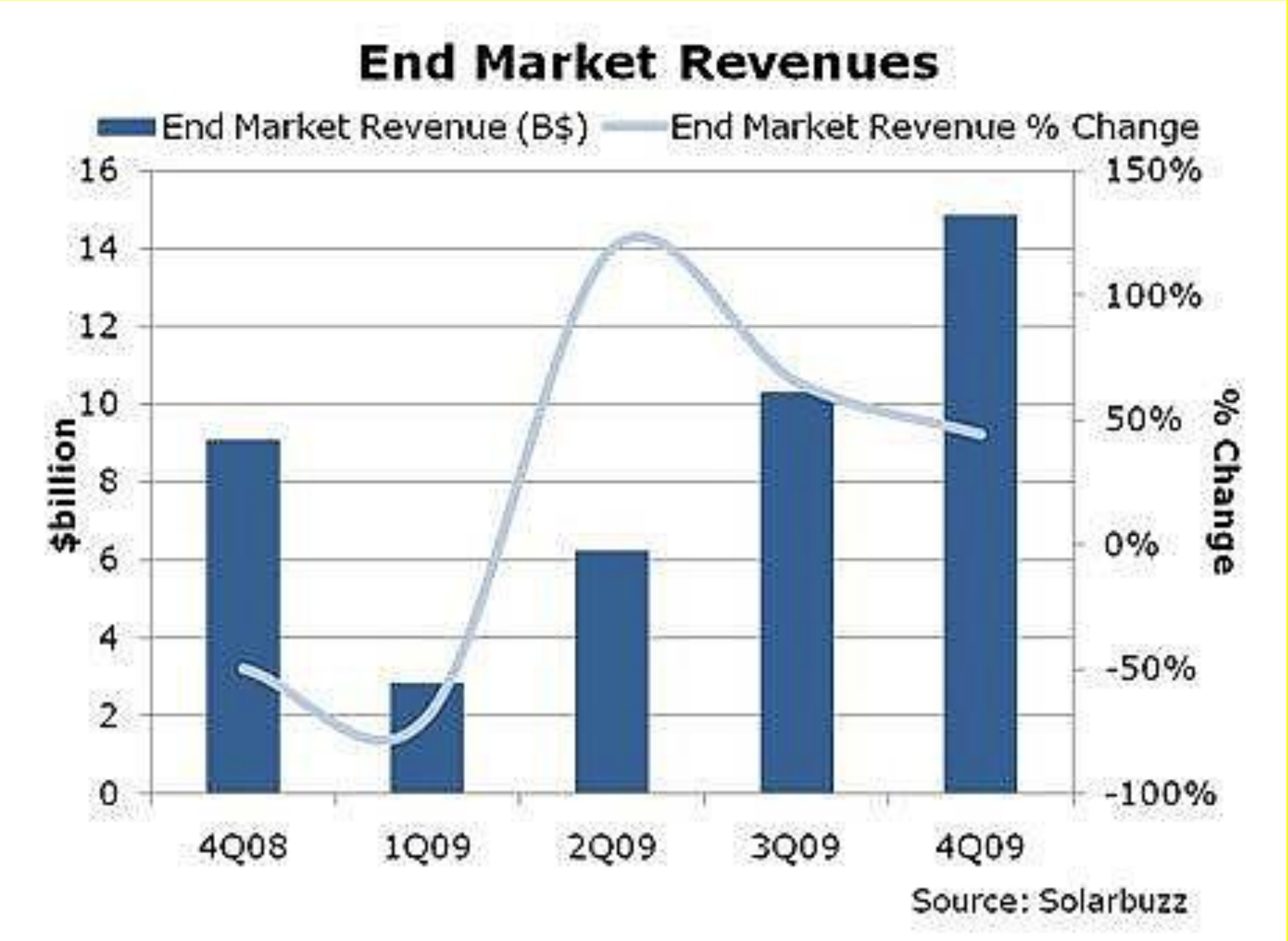
Recession, conservative, and accelerated forecasts, 2003 to 2013. *(Source: Navigant Consulting):* ‘*The recession forecast was declared as the most likely for 2009…..*’

Evolution of annual PV sales by countries in last decade



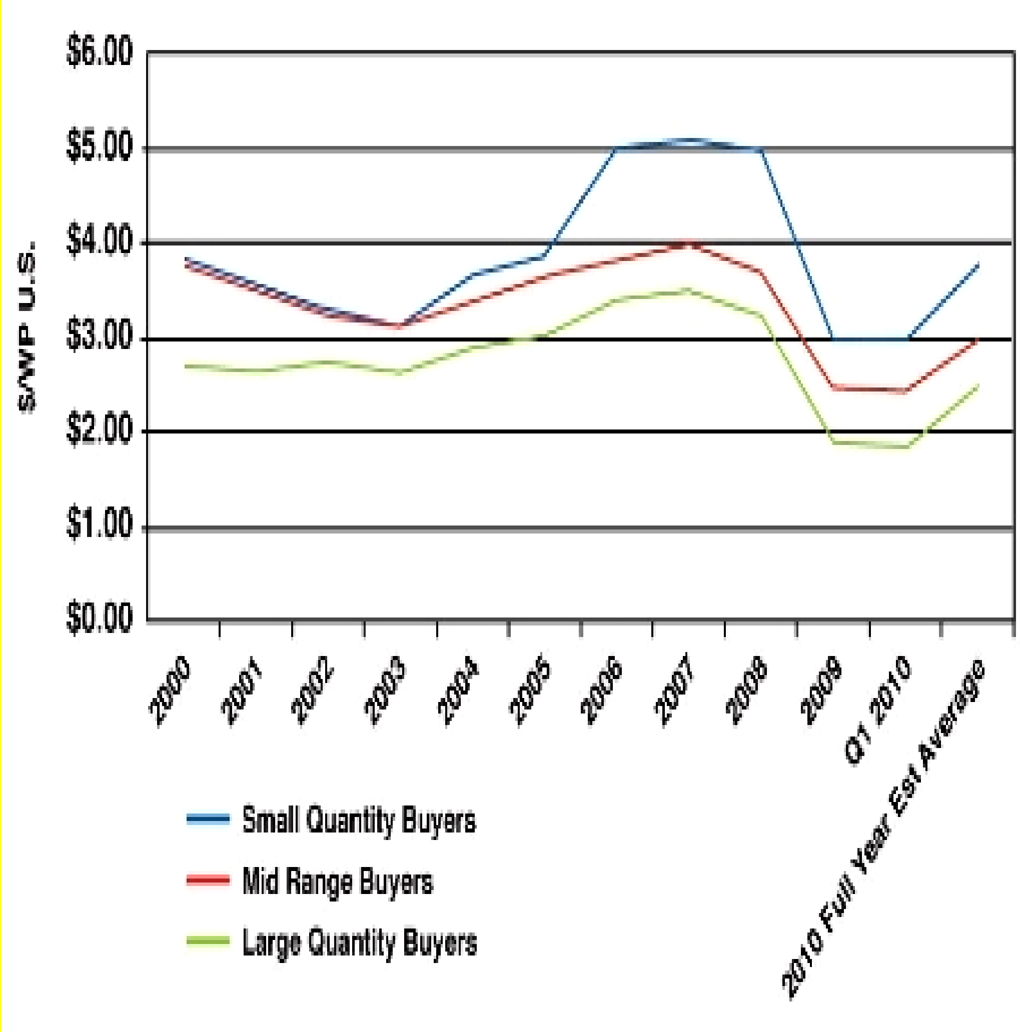
Hence, 2009 was still another very successful year for PV!

The dinamics of sales/revenues of PV industry during y. 2009



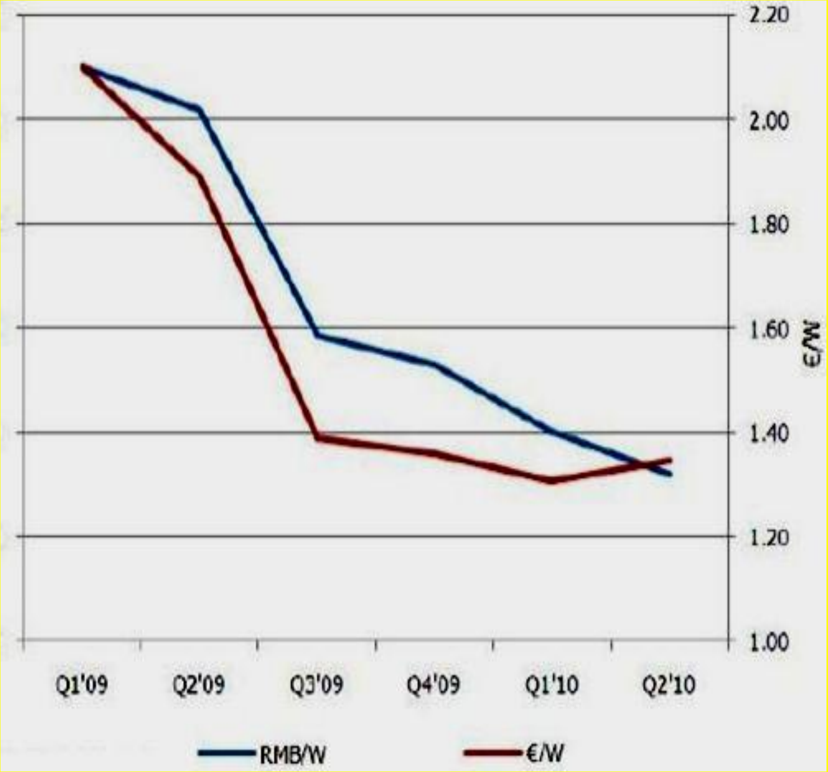
First quarter of 2009 seemed to confirm the recession scenario for 2009
However, the success in third and even more in forth quarter exceeded all expectations

2009: The Year Pricing Became an Extreme Sport - Till the end of the year 2009 prices almost halved



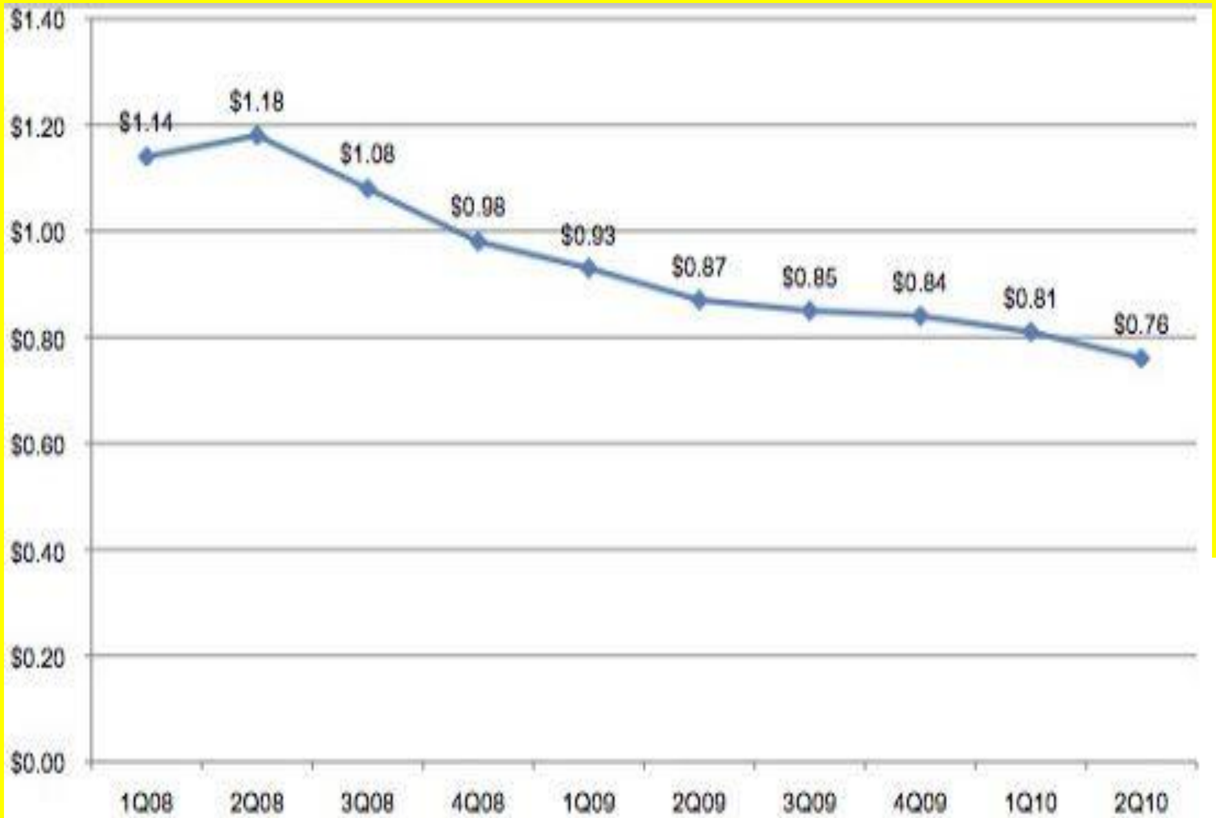
By the fourth quarter **prices to large buyers averaged $1.90**, with reports of prices **as low as $1.40/Wp .**

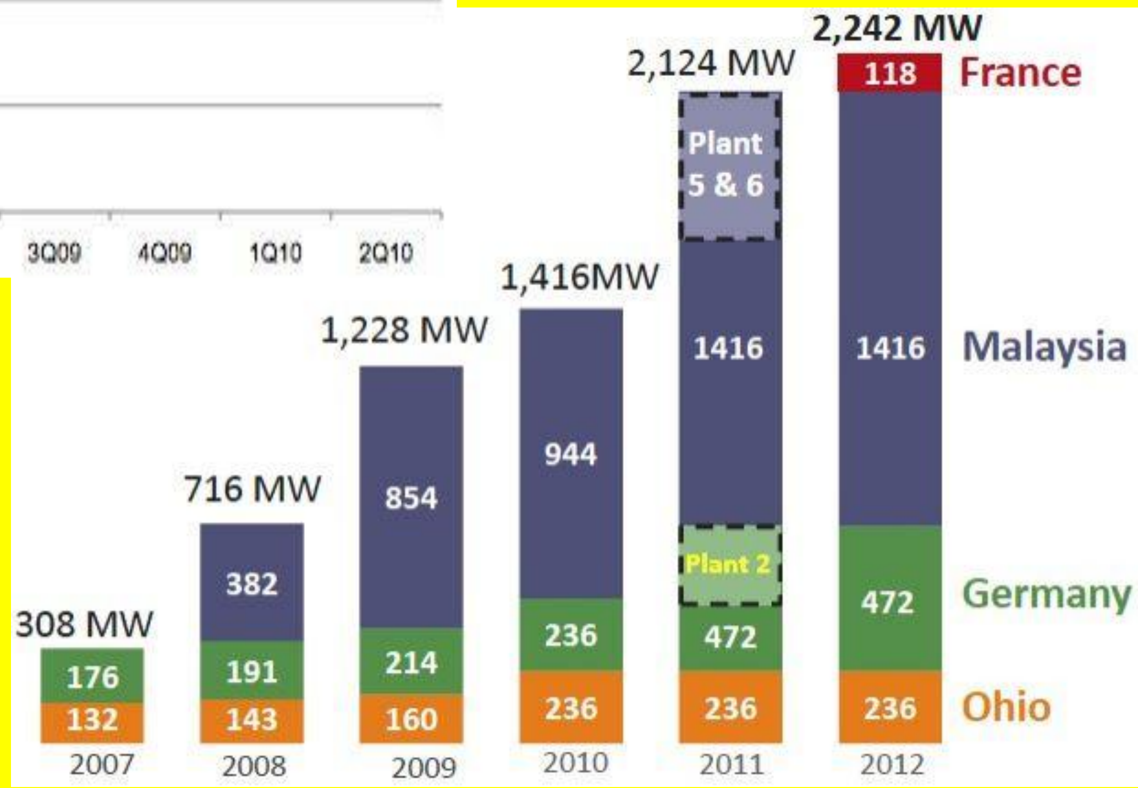
Buyers of all sizes enjoyed prices below $3/Wp



PV module price/W_p In **2010** *(Source: IMS Research)*

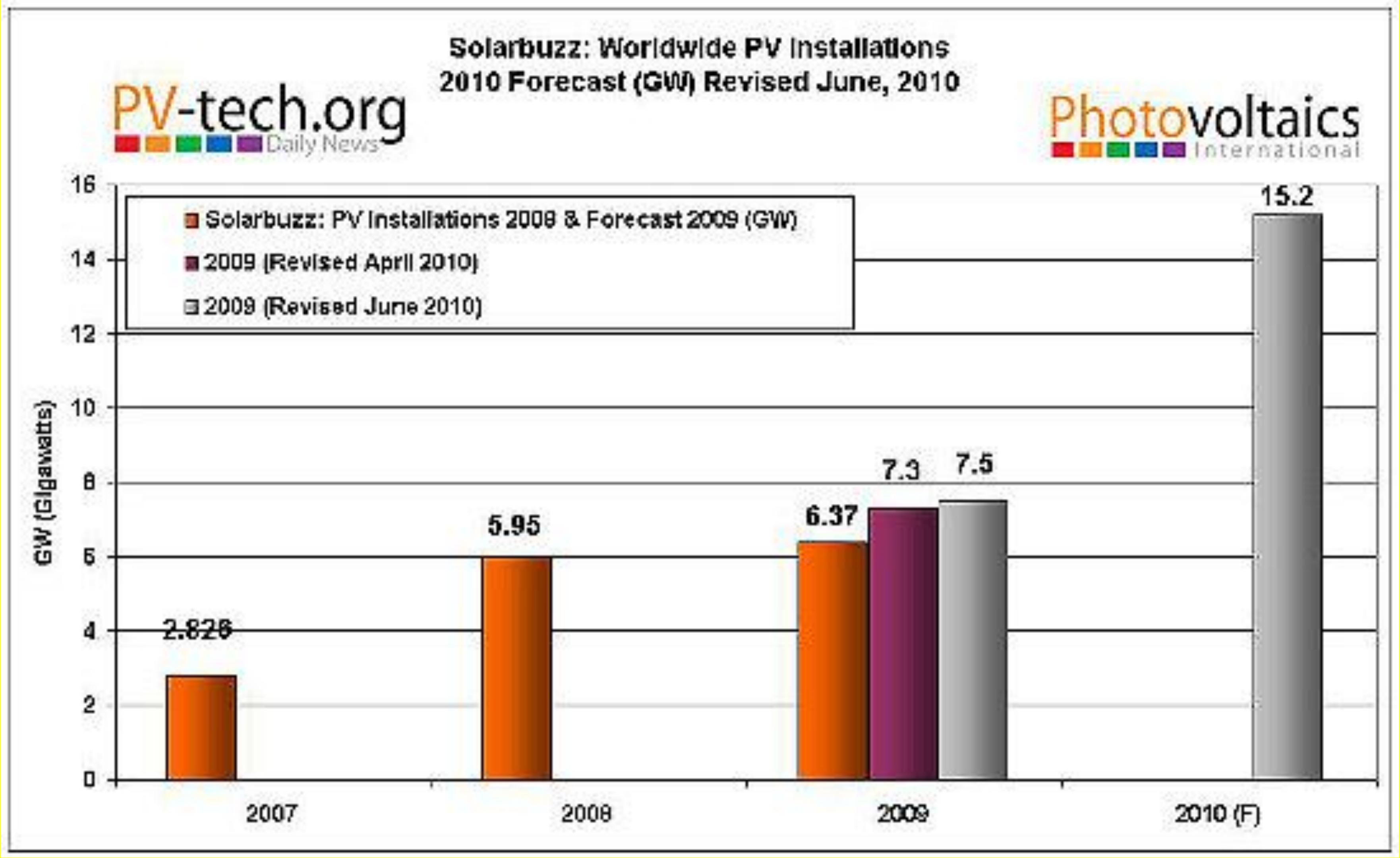
Trends in Manufacturing Costs for *First Solar* (CdTe) in 2010





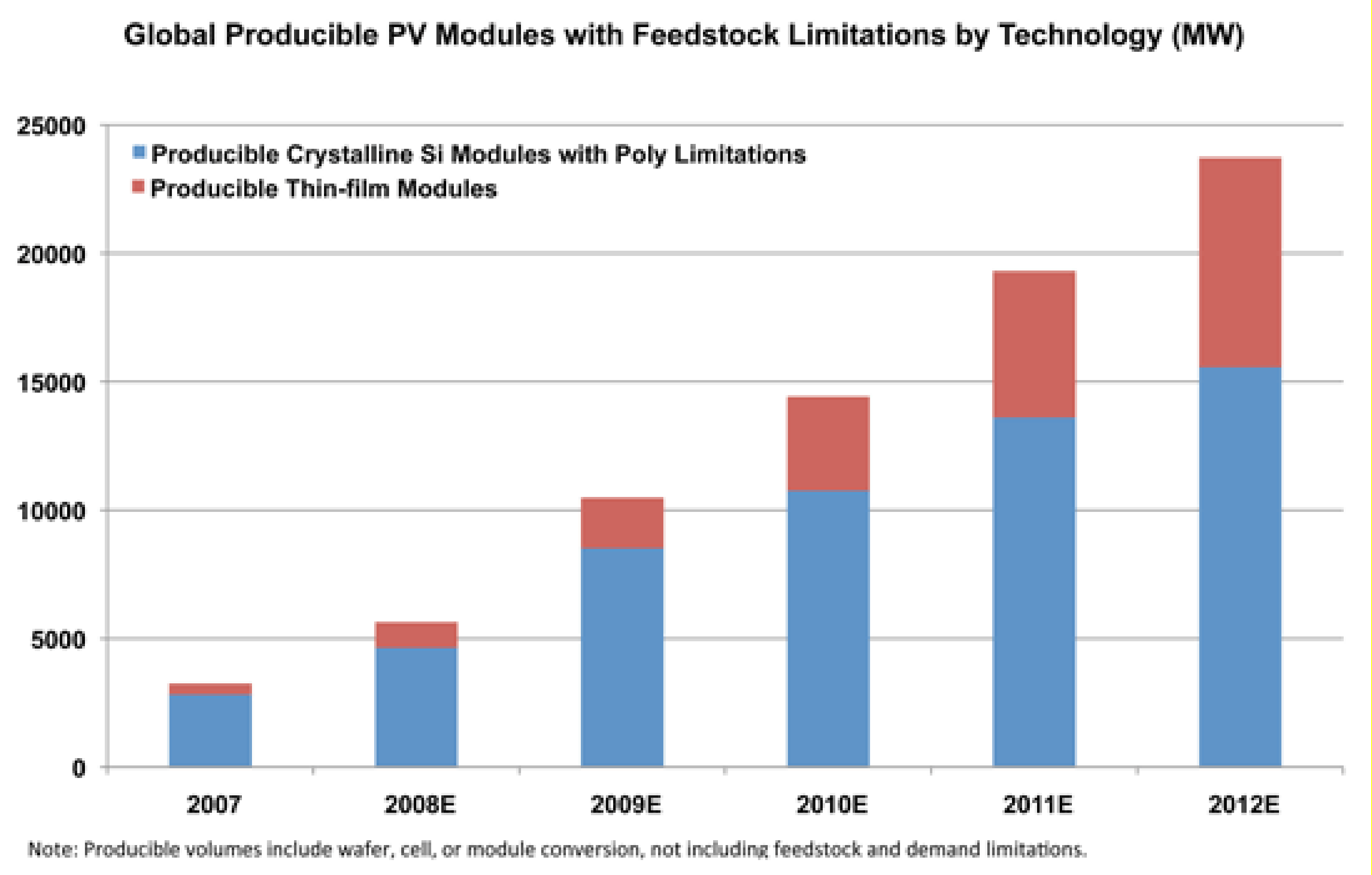
Trends in Manufacturing Production Capacity, as ¸announced by *First Solar* (CdTe) for 2010 and further

Prospects/Forecasts for year 2010….



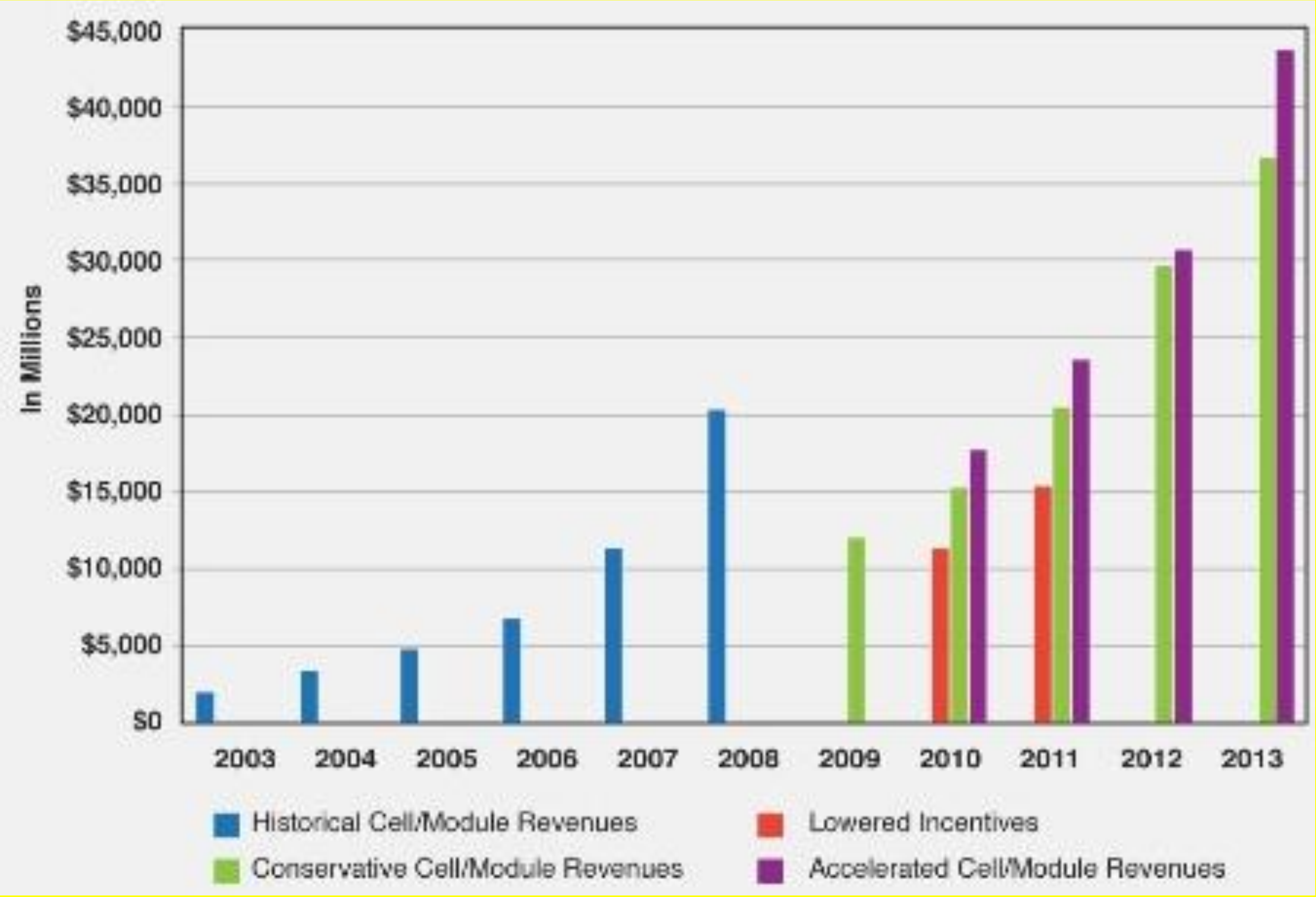
Forecast for this year is again extremely optimistic, and about doubling of installation growth is expected

Prospects in next few years….



- **Expected growth of PV capacity in 5 years: 4,8x !**

Due to drastic fall of PV cell/module prices the **revenues (and even more profits) of PV industry decreased** in 2009 but PV industry in general not only survived well but further high growth is expected, even if incentives are lowered



Why PV future looks so bright?

General:

Ecological, social & political reasons are giving strong push to the field

Optimistic recent news:

- In some countries (U.S.A., China, Japan, England, Belgium...) there are very optimistic forecasts about future growth of PV

For example in U.S.A., as one of key countries (third market, after Germany and Italy)**:**
- T**enfold increase of capacity** is expected within the next five years
-Obama signed into law ***Ten milion roofs program*** in July 2010

- The low-cost Chinese manufacturers have announced **PV capacity additions totaling over 2 GW,** to be operational by **the end of 2010.**

-Etc.

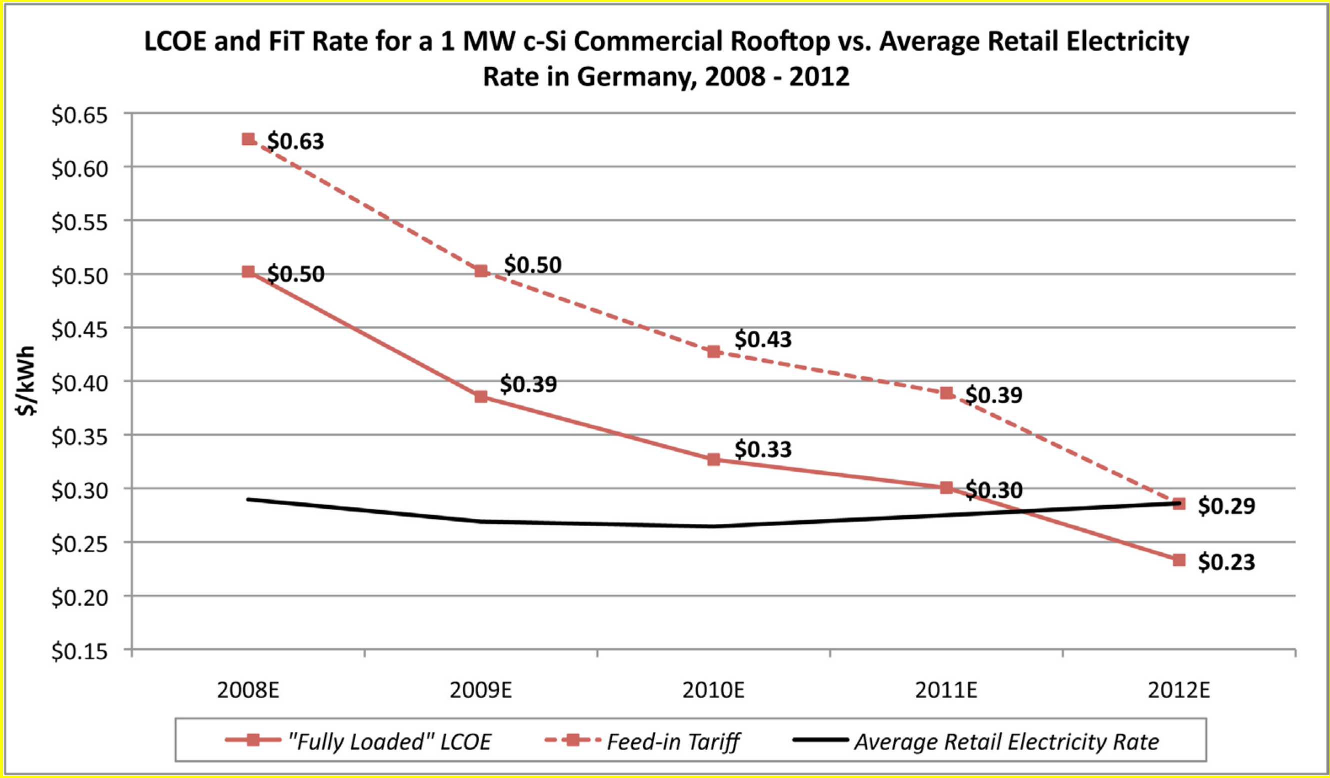
Why PV future looks so bright? (2)

Grid parity (i.e., where price of solar electricity is equal to price of grid electricity) **will be reached soon:**

-The **US** has set 2015 as a goal to reach **grid parity withouth subsidies**

-- **EU predicts** reaching it **as soon as 2010** (starting with southern EU) .

- Then a **resurgence** is expected in **investment, development, and innovation** throughout the world



Why PV future looks so bright? (3)

ADDITIONAL HUGE POTENTIAL FOR FURTHER REDUCTION of PV ELECTRICITY PRICE :

a) Technological improvements of solar cell/module production

b) Integration of PV into building and other industries

REDUCING PRICE OF PV ELECTRICITY:
Technological improvements of solar cells/modules production

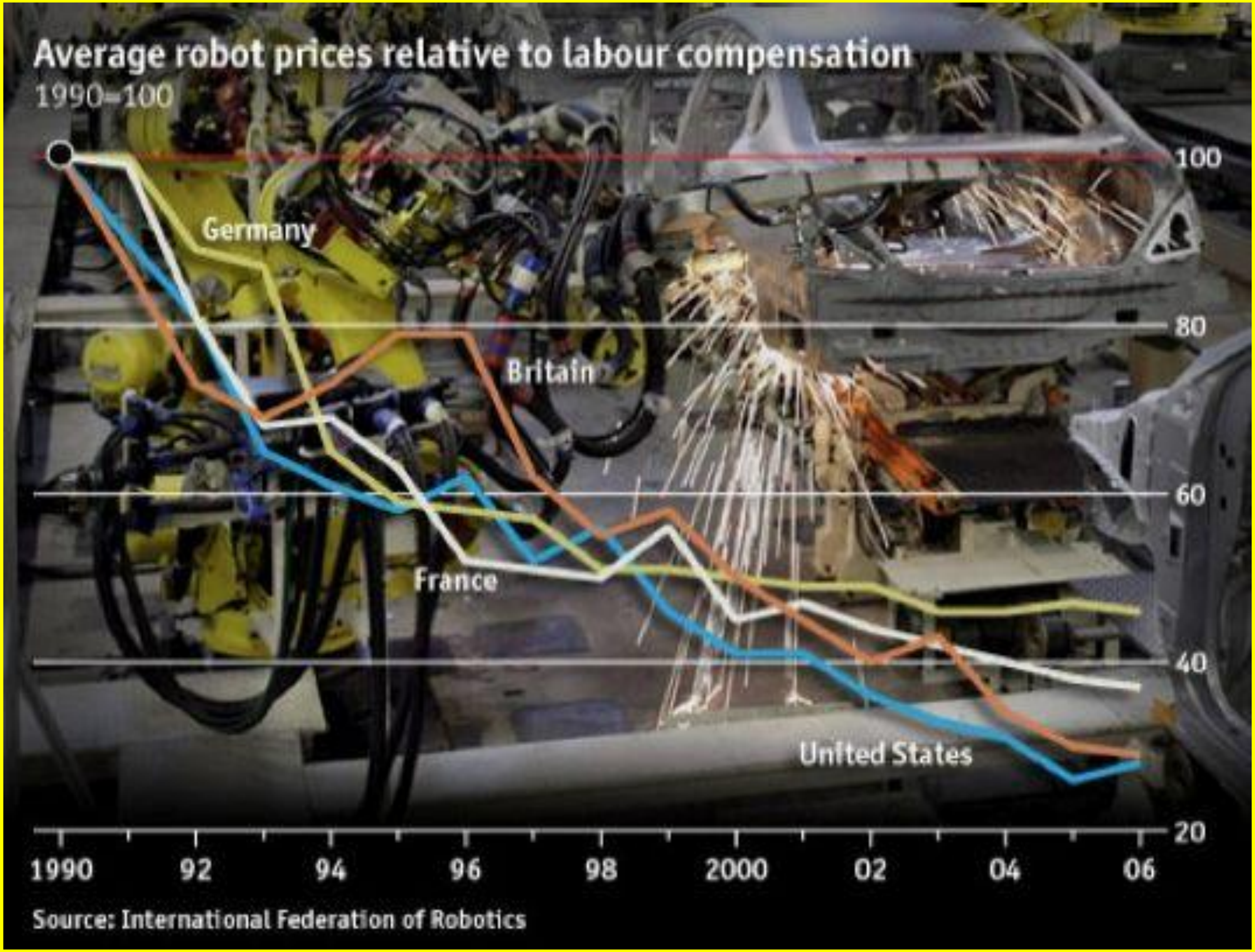
Figure : System build process flow. (Crystalline Silicon)

PRODUCTION AUTOMATIZATION and ROBOTISATION

in the photovoltaic manufacturing process can significantly reduce costs, just as it happened in electronic industry

Presently, to put in use **one gigawatt** of solar power it requires:
250 to 500 laborers to produce polysilicone,
250 to 500 laborers to process ingots, **3000-6000 people** to manufacture the cells, **1500-3000** for the panel lamination and associated applications and
2500-5000 for the solar system integration**.**
In total that's **8000-16000 laborers** required to produce and instal **1GW** of photovoltaic capacity.

Robot prices (relative to labor cost) dropped significantly



Average robot process costs relative to labor compensation. SOURCE: R. Swanson/SunPower

REDUCING PRICE OF PV ELECTRICITY:

Building Integrated Photovoltaic (BIPV) modules:

BIPV modules - not an add-on to the building, but an integral part of the building skin with the added value of generating electricity.

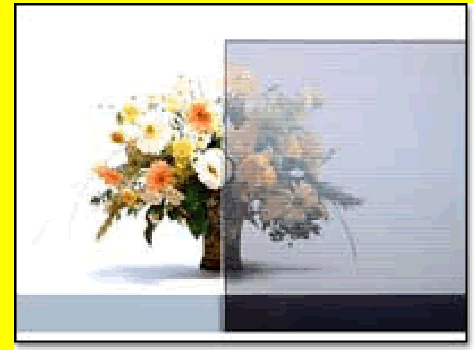
100m^2 roof is receiving US $300.000 value of electricity over 25 years

The BIPV market is expected to explode:
To about US $800 million in 2011
and surpass US $8 billion in 2015.
(Source: *NanoMarkets* research firm)

PV Building Integrated Technology

Thin film cell can be made flexible

…or Semi-Transparent



New PV technologies that can be integrated with other building elements (Windows, Skylights, Roffs etc.) - or replace them

Solar Windows

Solar Skylights

Solar Roofing Products

BIPV examples

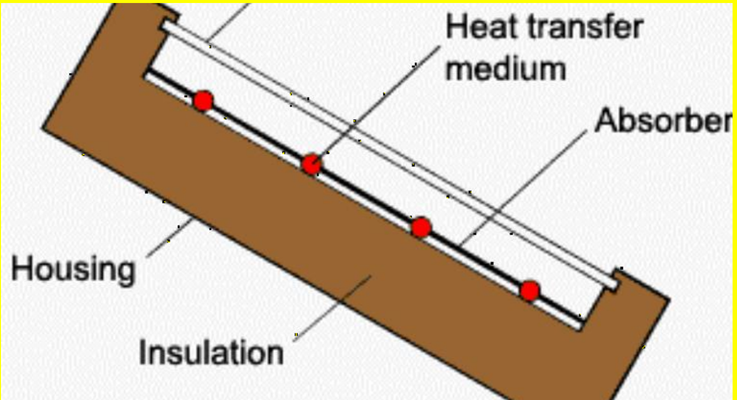
Electricity-producing roof tiles

Uni-Solar's "peel and stick" laminates (made from a-Si) on two buildings in California

REDUCING PRICE OF PV ELECTRICITY: PV/T systems

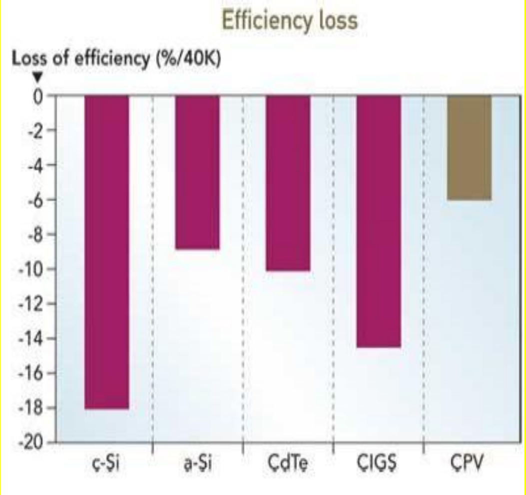
The development and commercialization of **hybrid PV/Thermal systems (produces electricity and Hot water). PV/T system quadruples the energy production of a traditional PV system**

Glass with semi-transparent PV layer deposited to inner surface



PV/T system

The Beijing Olympic PV/T system - the first large-scale PV/T in the world. The system was sized for **10 kW of PV and 20 kW of heating**



PV/T protects PV cell from overheating and thermal degradation, increase cell efficiency

Outlook for PV in EU

EU Context for accelerating PV growth:

In March 2007, the European Union adopted an integrated climate and energy policy. Ambitious quantitative policy goals, to implement by 2020, are:

- **Reduce greenhouse-gas emissions** unilaterally **by 20%** from 1990 levels;

- Ensure that **renewable energy** represents **a 20% share** of total energy use

- **Reduce overall energy consumption by 20%.**

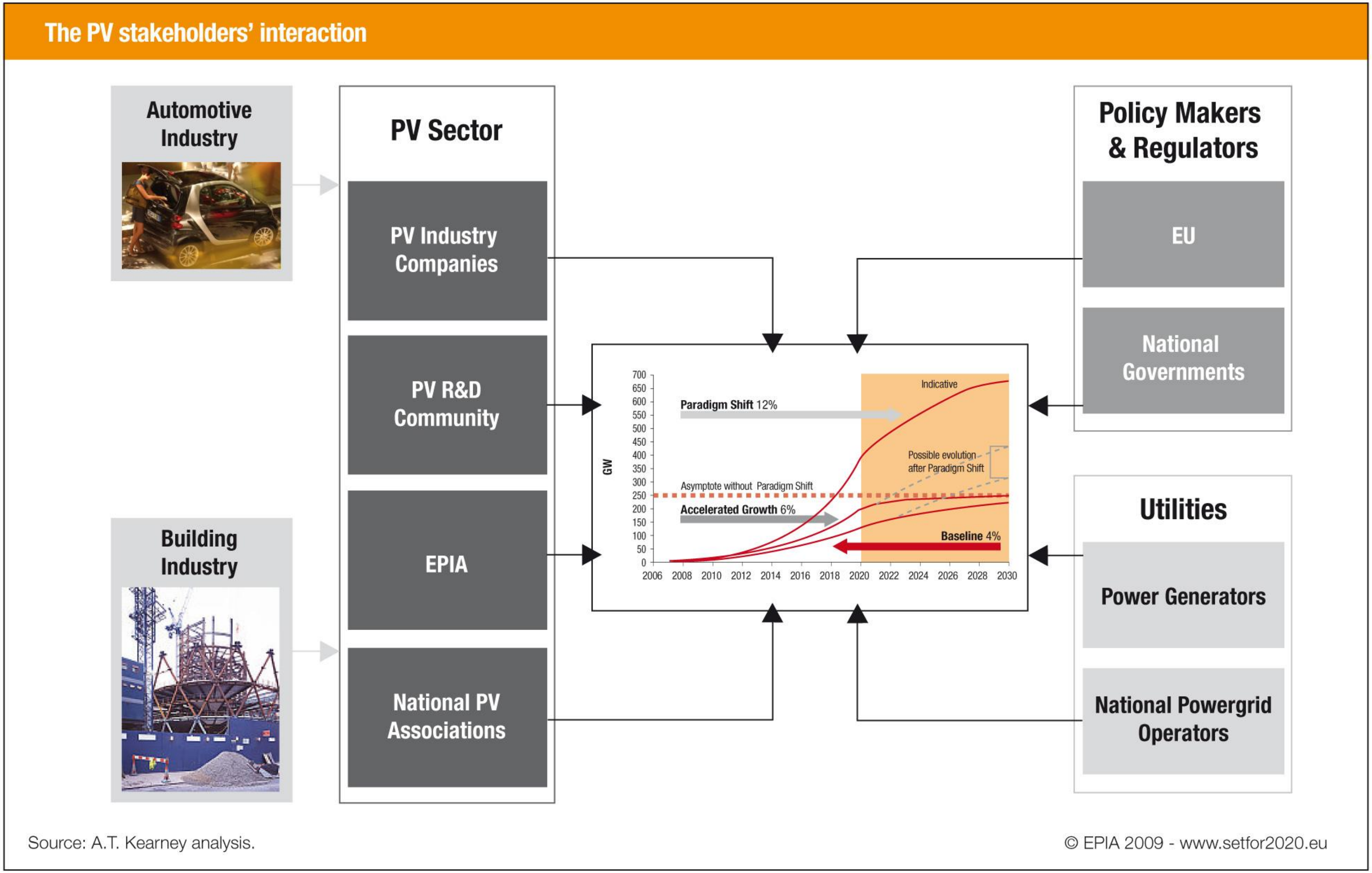
The **so-called "20/20/20" goals** are underpinned by a broader EU policy rationale to:

- Promote environmental sustainability and combat Climate Change;
- Increase the security of energy supply;
- Support the EU economic competitiveness and the availability of affordable energy.

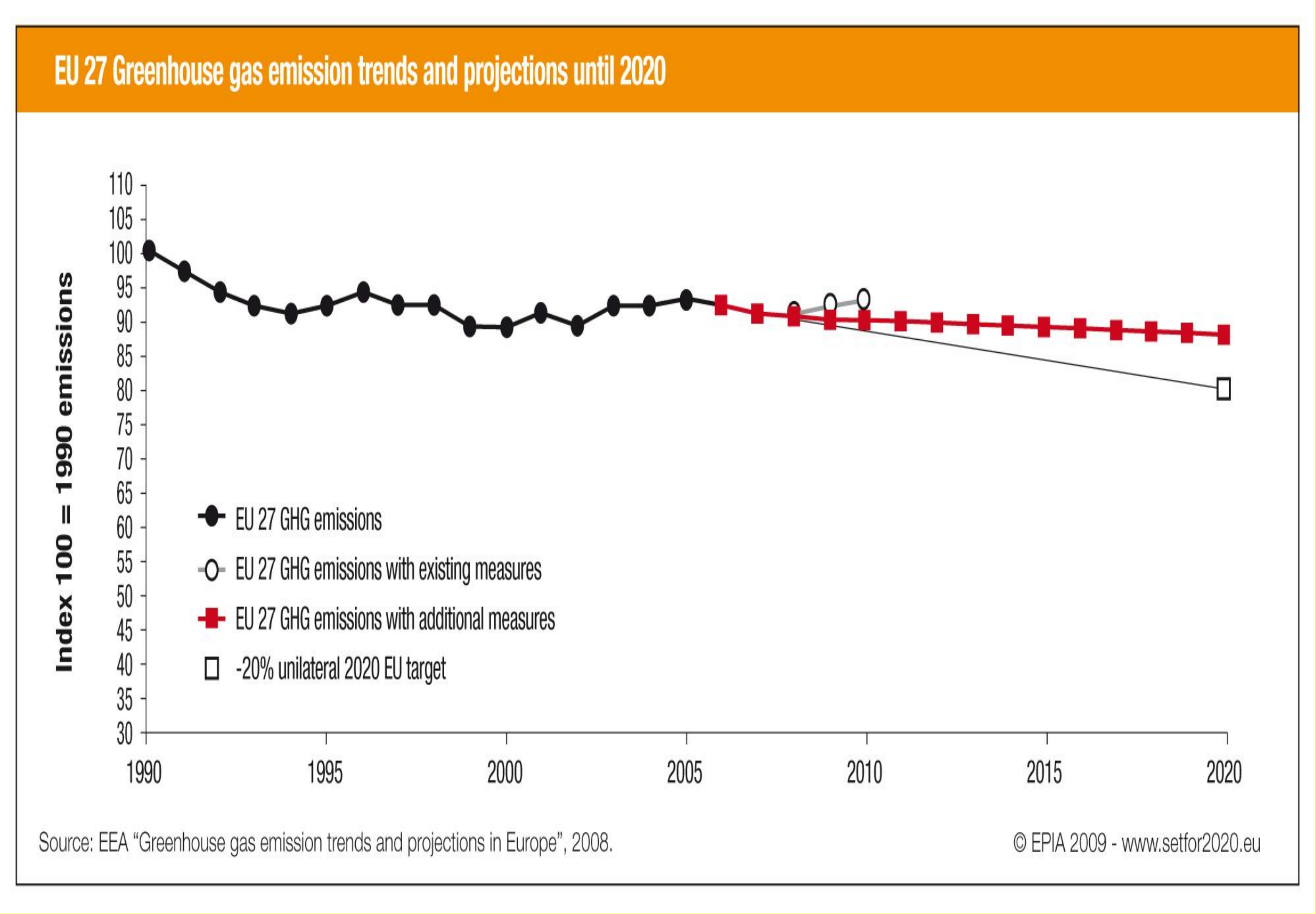
Dramatically increasing the share of PV in the European electricity market will support all of these objectives and help the EU meet its 20/20/20 targets.

The EPIA study: **PV** could provide up to **12% of the EU electricity** demand by **2020 (the share of all RES: 35%)**

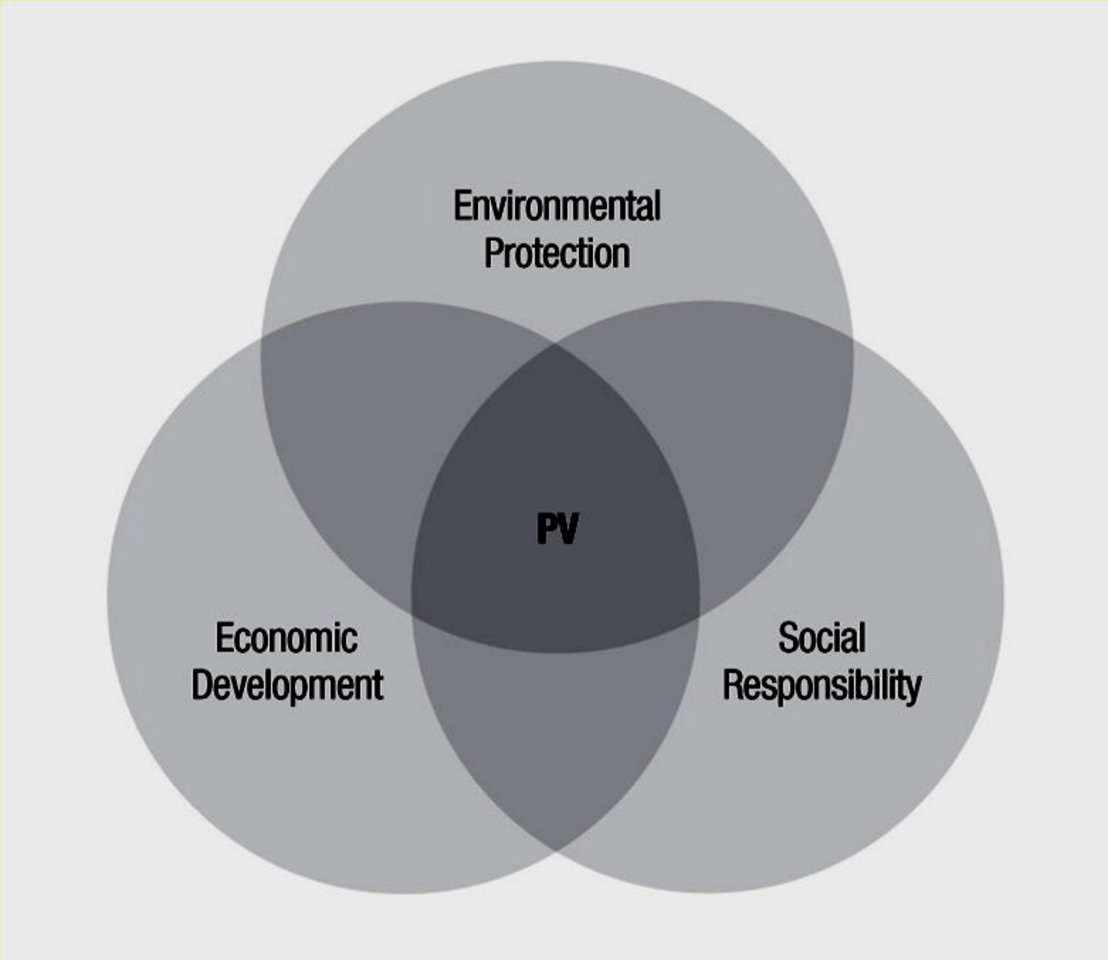
The roadmap to this goal, with the defined role of all stakeholders: www.setfor2020.eu



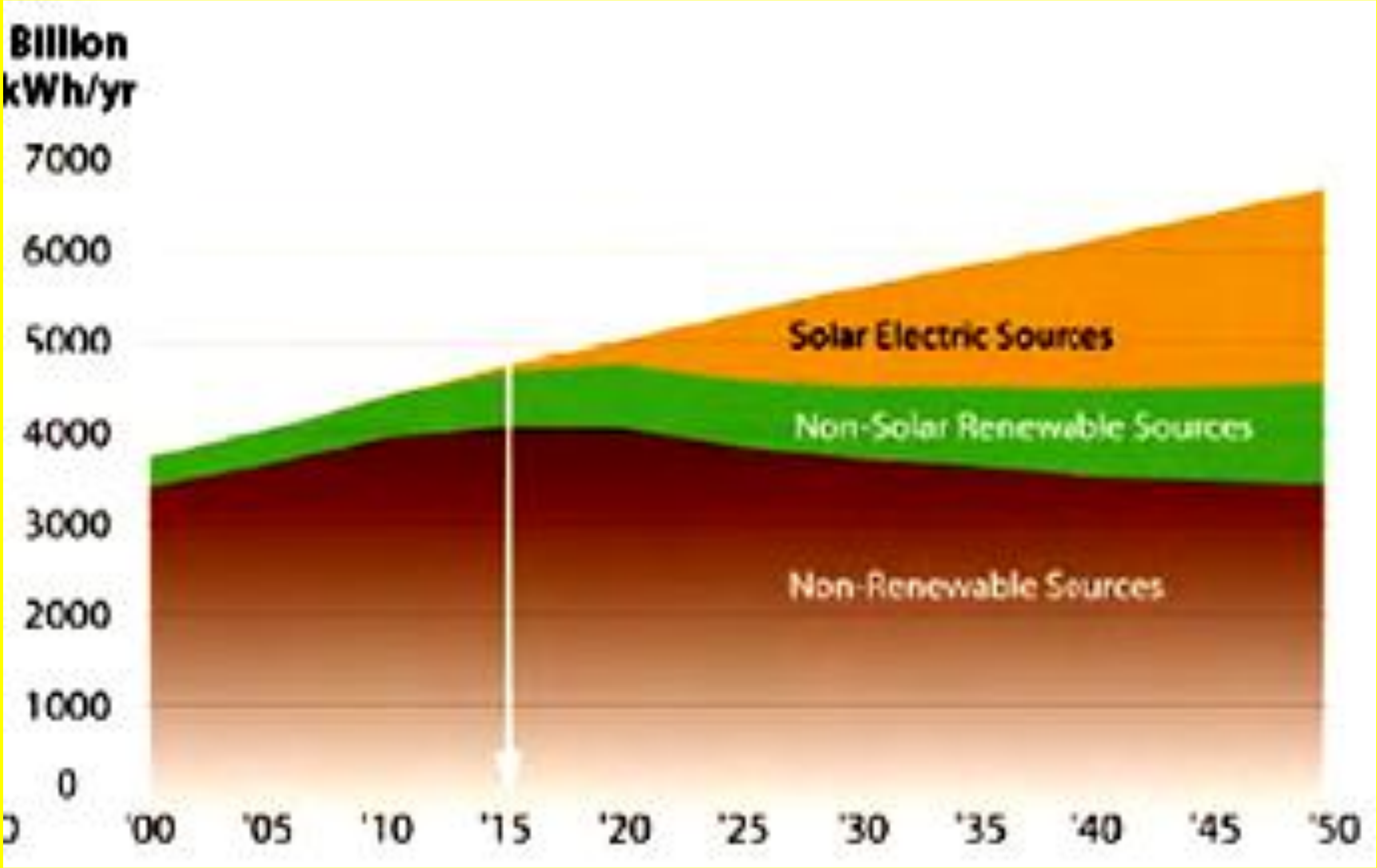
A 12% market share for PV is not only desirable objective, but also a precondition for reducing the geennhouse gases emission.



PV can make an important contribution to the EUs policy objectives and provides additional benefits besides clean electricity – a socially responsible, ecologically sound and sustainable economic development



Long term prognoses, up to 2050 (Source: Fraunhofer Institute, 2006):



CONCLUSIONS

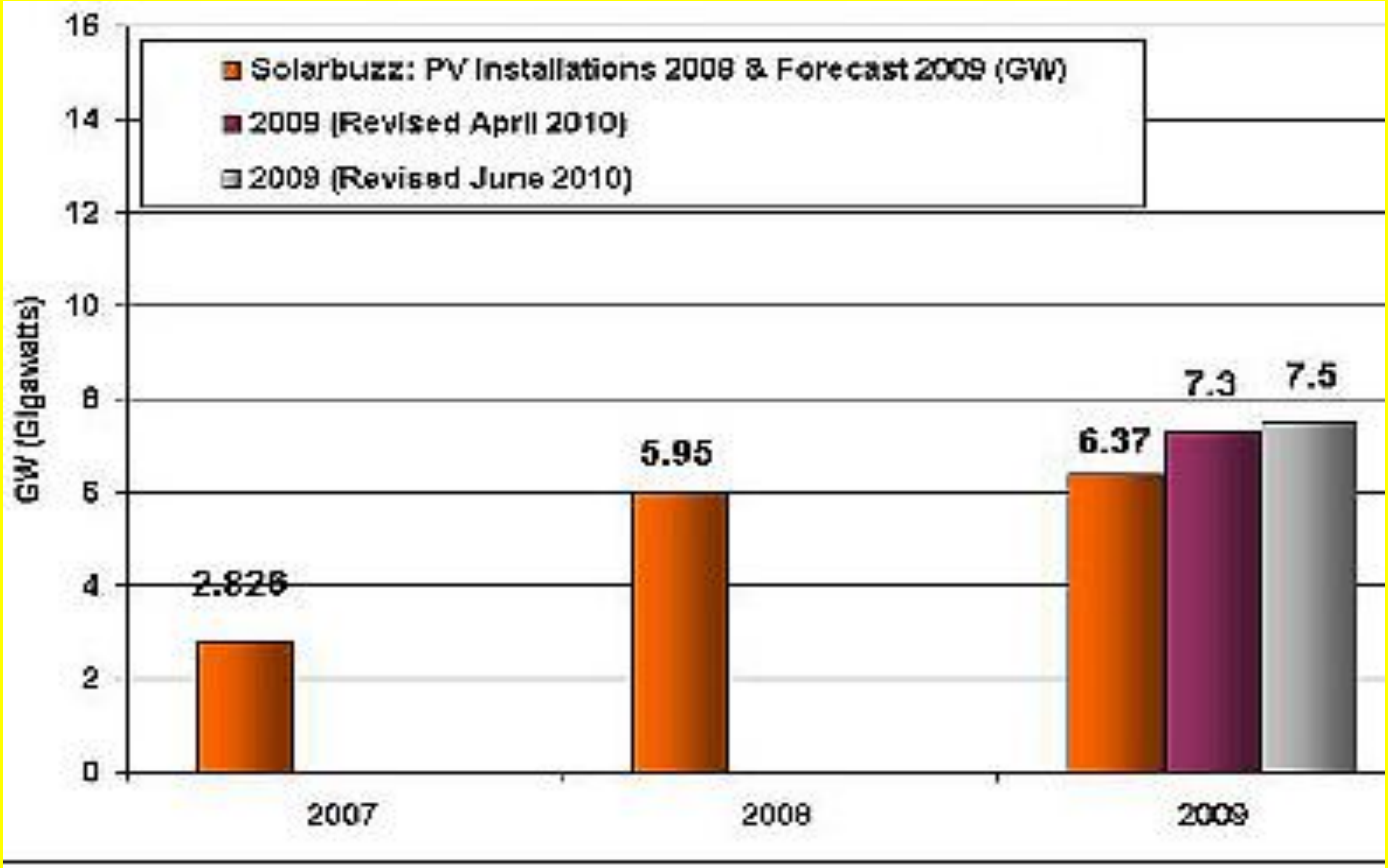
The solar energy is the only energy source that is practically limitless

“Grid parity” is expected to be reached very soon

PV is a very young and fast-developing industry, with a very high potential for further substantial cost reduction.

Clean solar electricity can substantially reduce our ecological and CO_2 emission problems

PV has substantial social, political and ecological advantages to significantly contribute to the prosperous and sustainable development of EU and our civilization

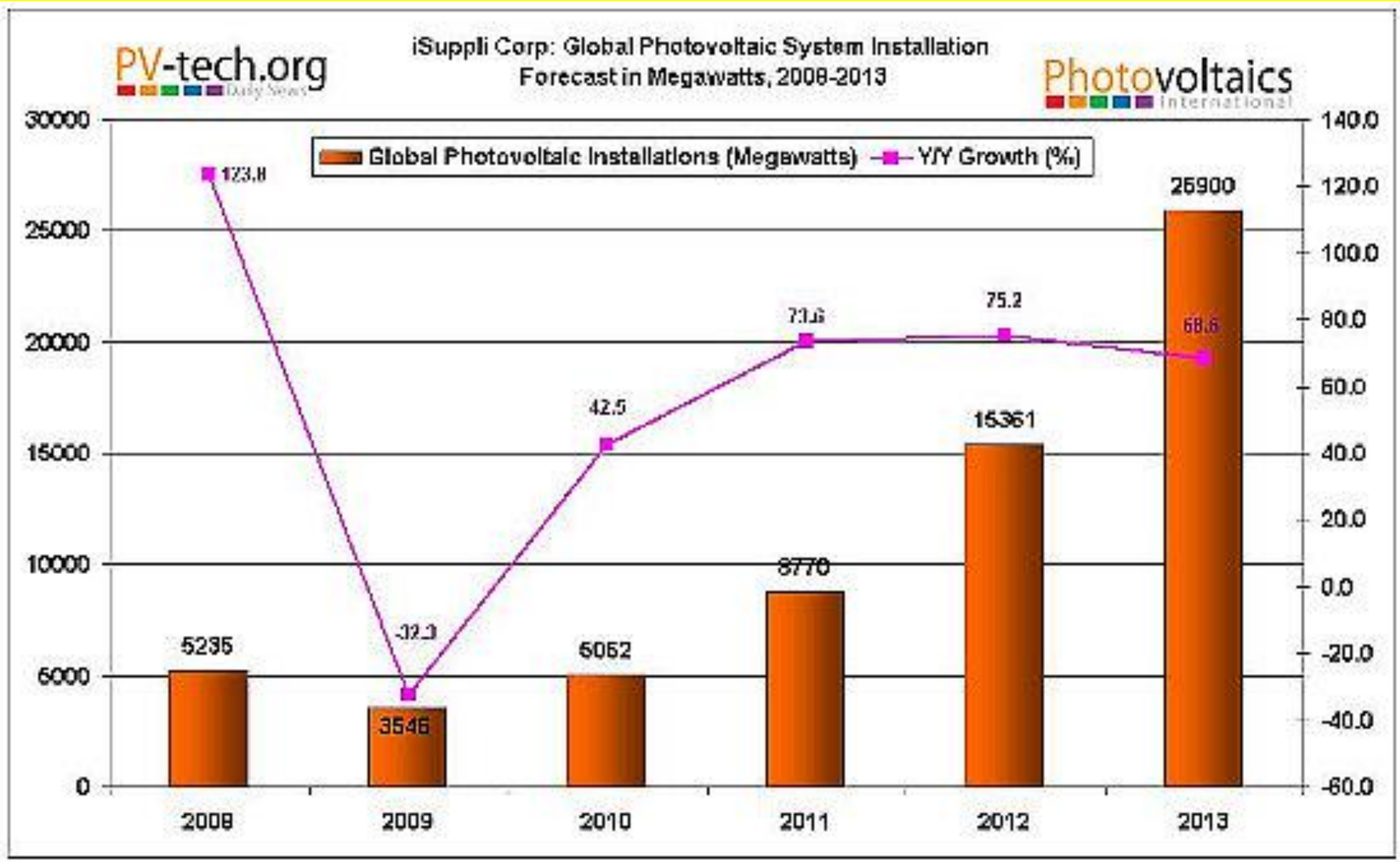


Revised figures (June 2009) when even higher than preliminary figures, issued in March. They came from upward revisions in some countries. For example, revised. Installations in Italy reached 720 MW, (up significantly from 338 MW in 2008)

PV – FUTURE PROGNOSES

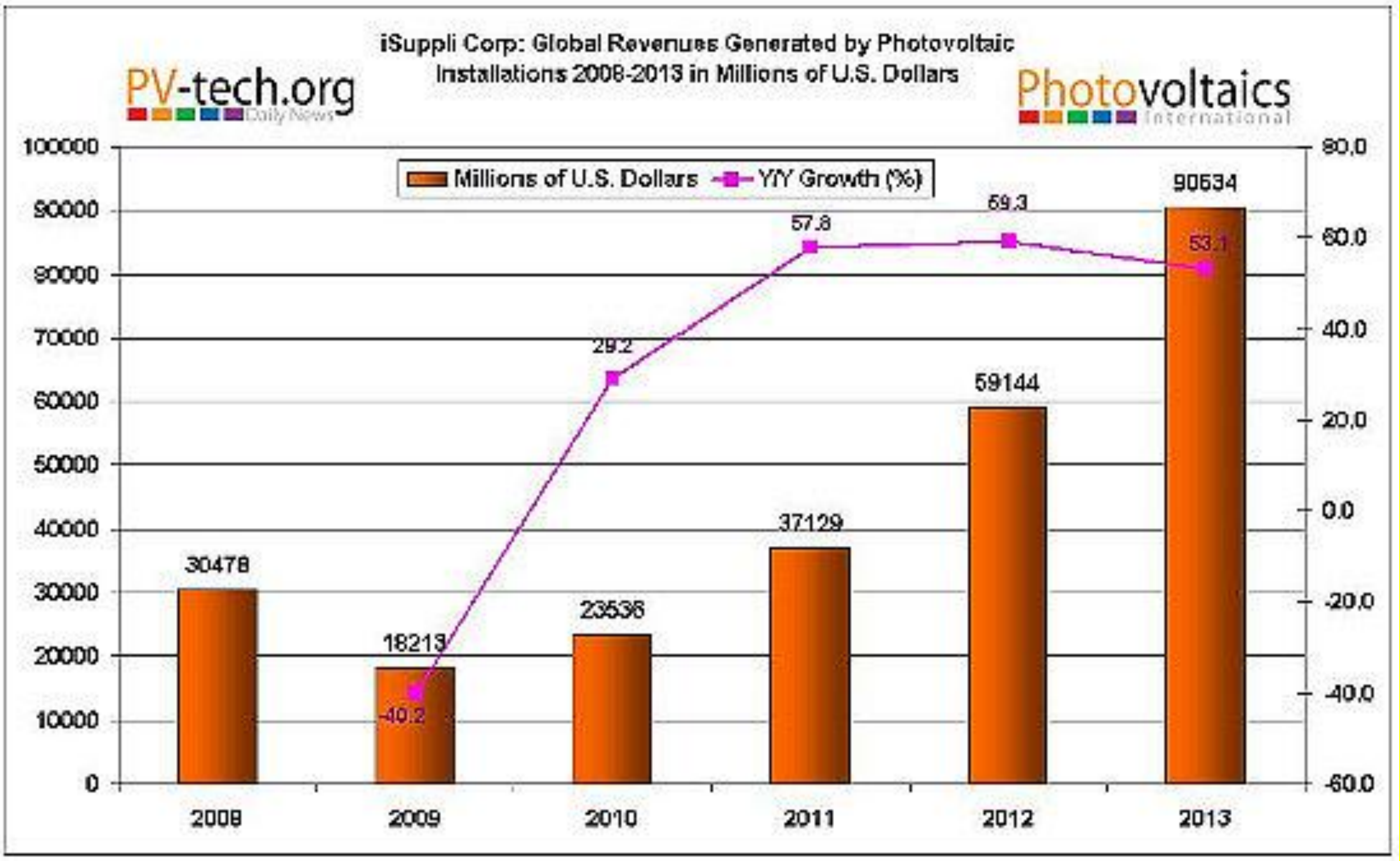
Forecasts for PV system installations

(forecast: *iSuppli*)

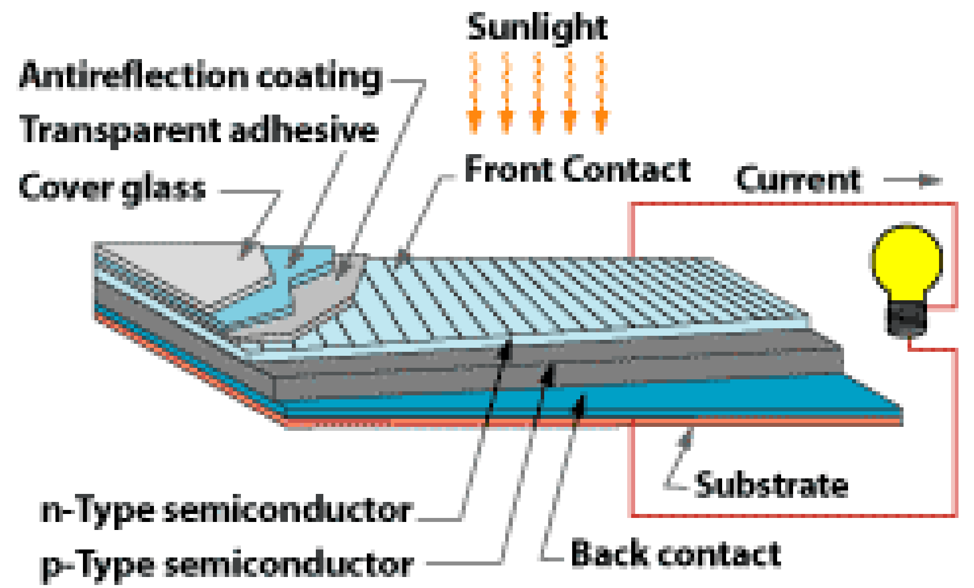


PV – FUTURE PROGNOSES

Forecasts for **PV Revenues** generated by PV installations in 2008-2013



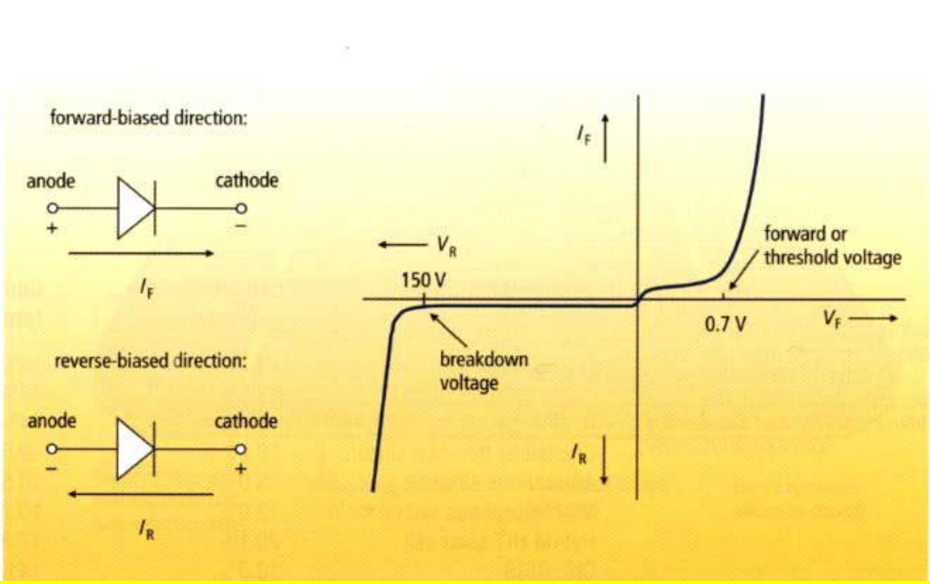
Crystalline Silicon Solar Cell and Cell efficiency



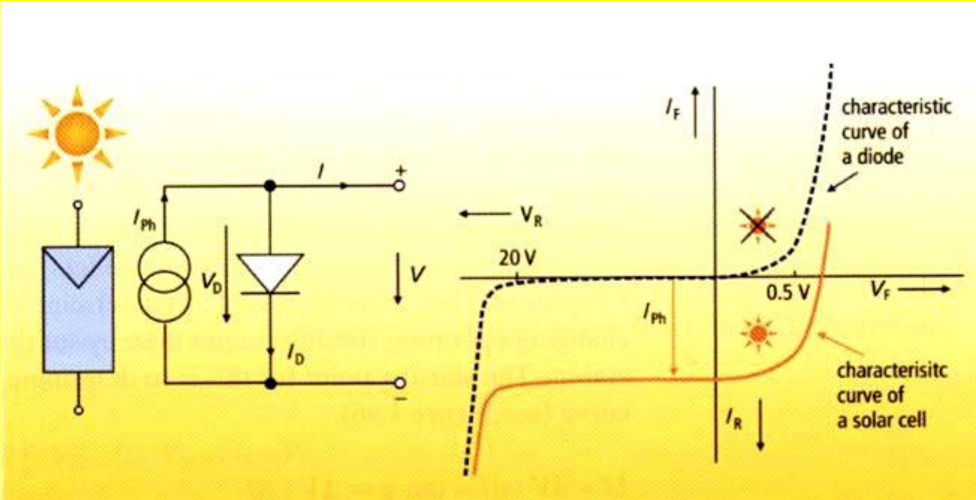
Solar cell efficiency: ratio of: <u>electrical output power</u> of solar cell, and
the <u>optical power of incident solar light</u>; (both measured in (W/cm2)

Some efficiency losses are <u>influenced by the cell design</u>:

- ***Front contact losses: Gridlines and bus-bars influence shading***
- ***Light reflection losses: Antireflection coating reduces reflection losses***
- ***Wafer thickness influences***



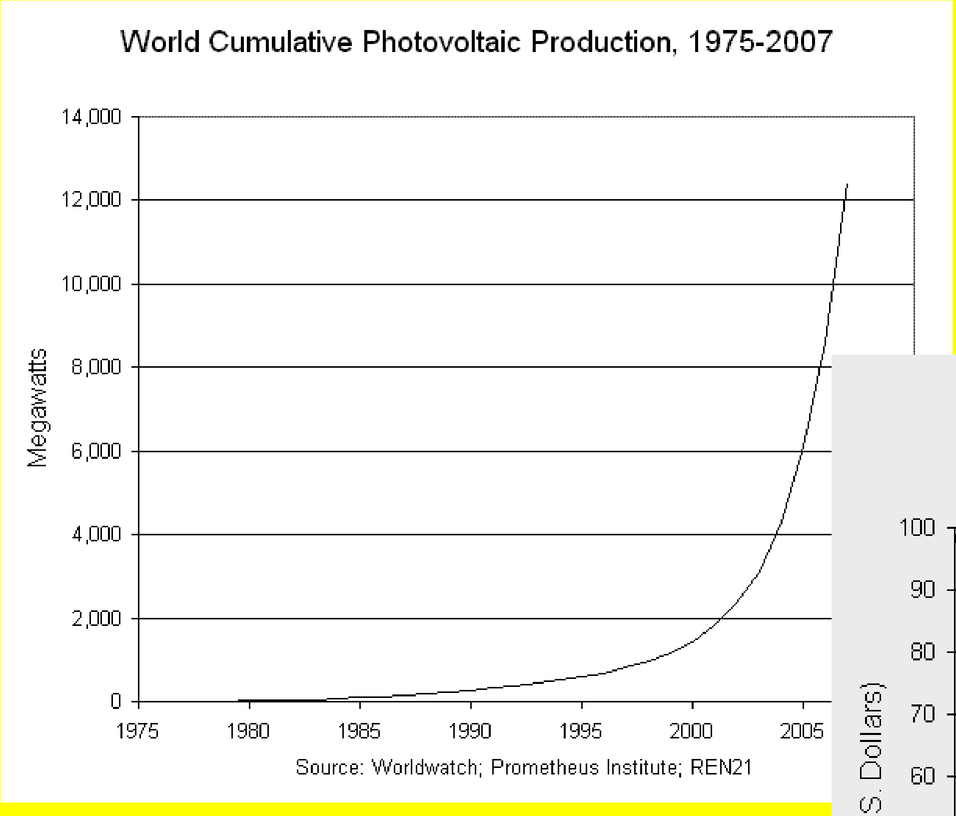
p-n diode characteristic

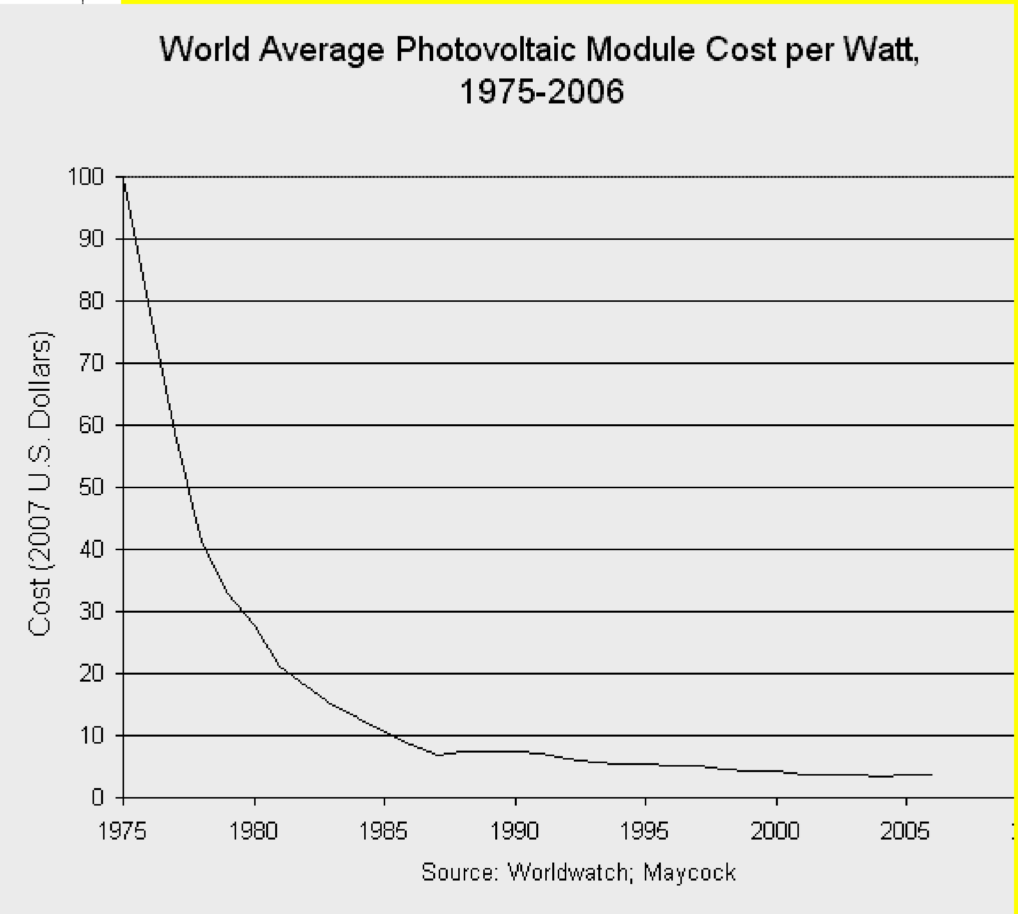


Equivalent circuit diagram (in dark and under light)

Early days of PV (c-Si solar cells)

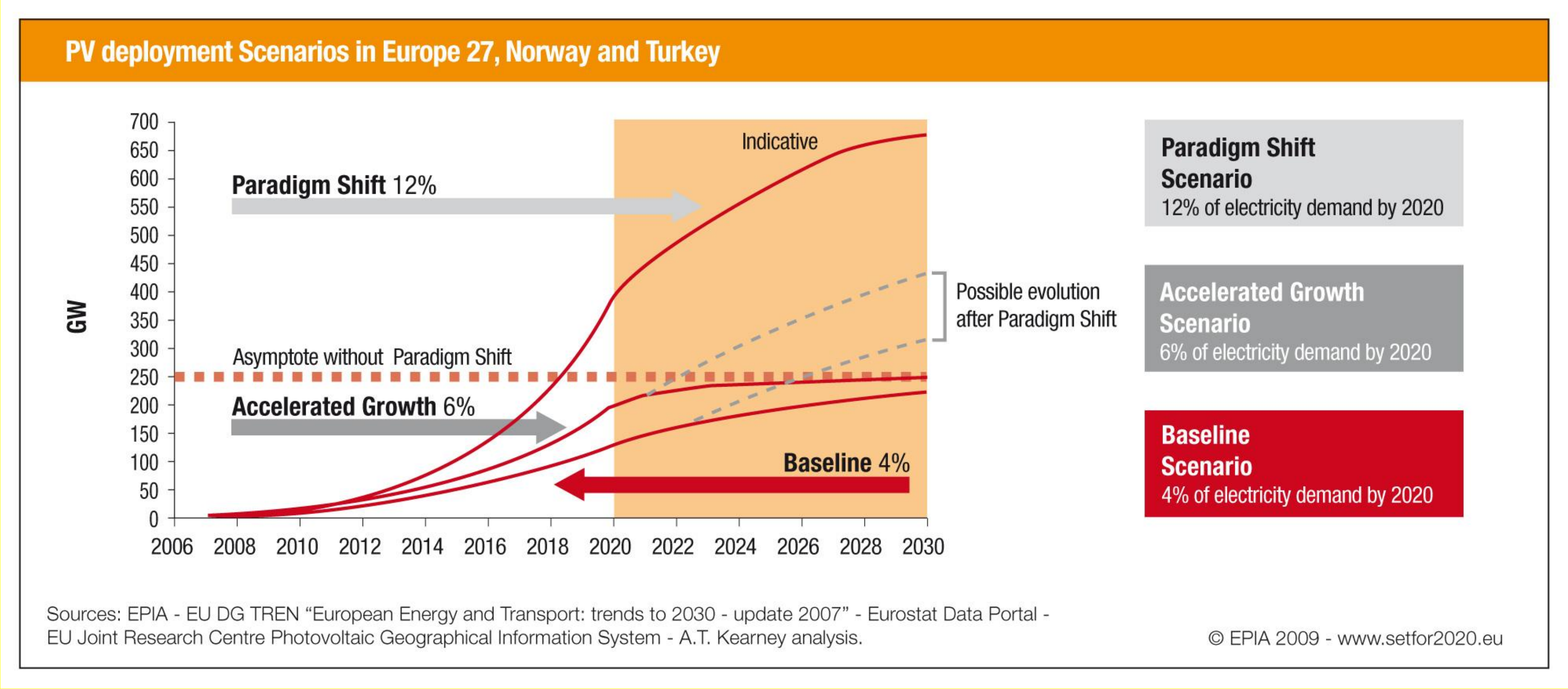
(up to 2005: over 95% of all Solar Cells were c-Si Solar Cells)





As with IC industry also enormous growth of production of solar cells and drastic fall of cell prices

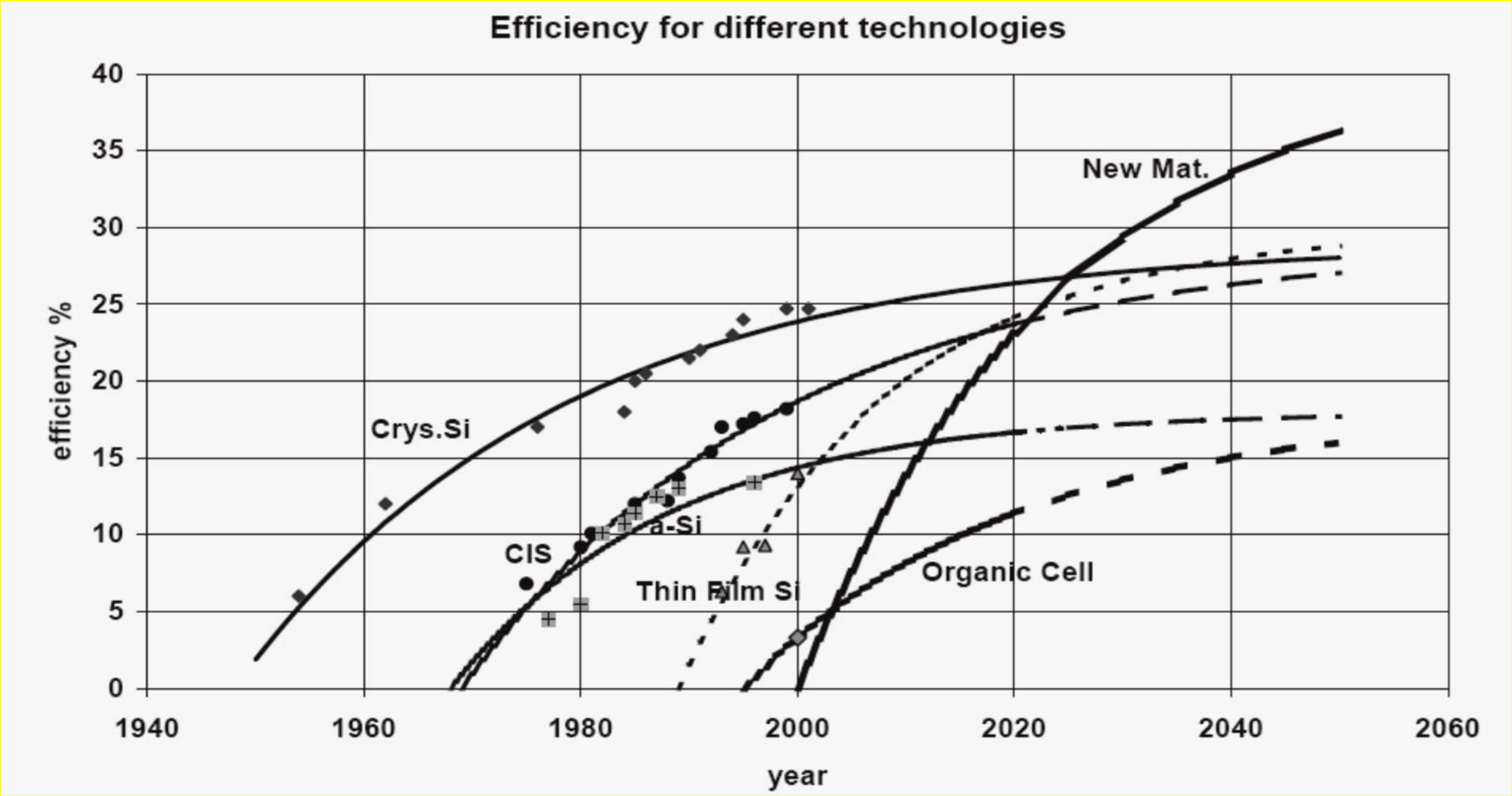
Outlook for PV in EU



The EPIA study demonstrates that PV electricity could provide up to **12% of the EU electricity demand by 2020, from less than 1% in 2007,** provided the right conditions are created by EU policy makers, national governments and energy industry stakeholders, including the PV sector.

A 12% market share for PV is a demanding, but achievable and desirable objective.

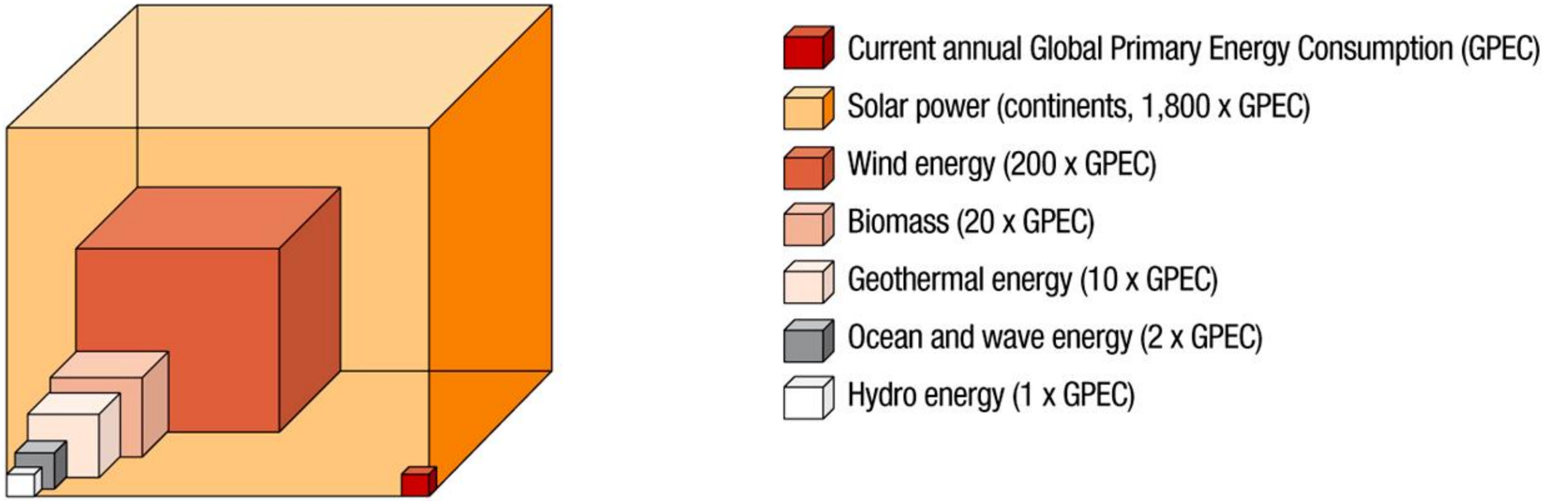
POTENTIAL FOR REDUCING PV PRODUCTION COSTS: Scientific/Technological developments to improve solar cell&module efficiency



Source: Prof. A Goetzberger

By transforming sunlight into electricity, PV uses a resource that has virtually unlimited potential

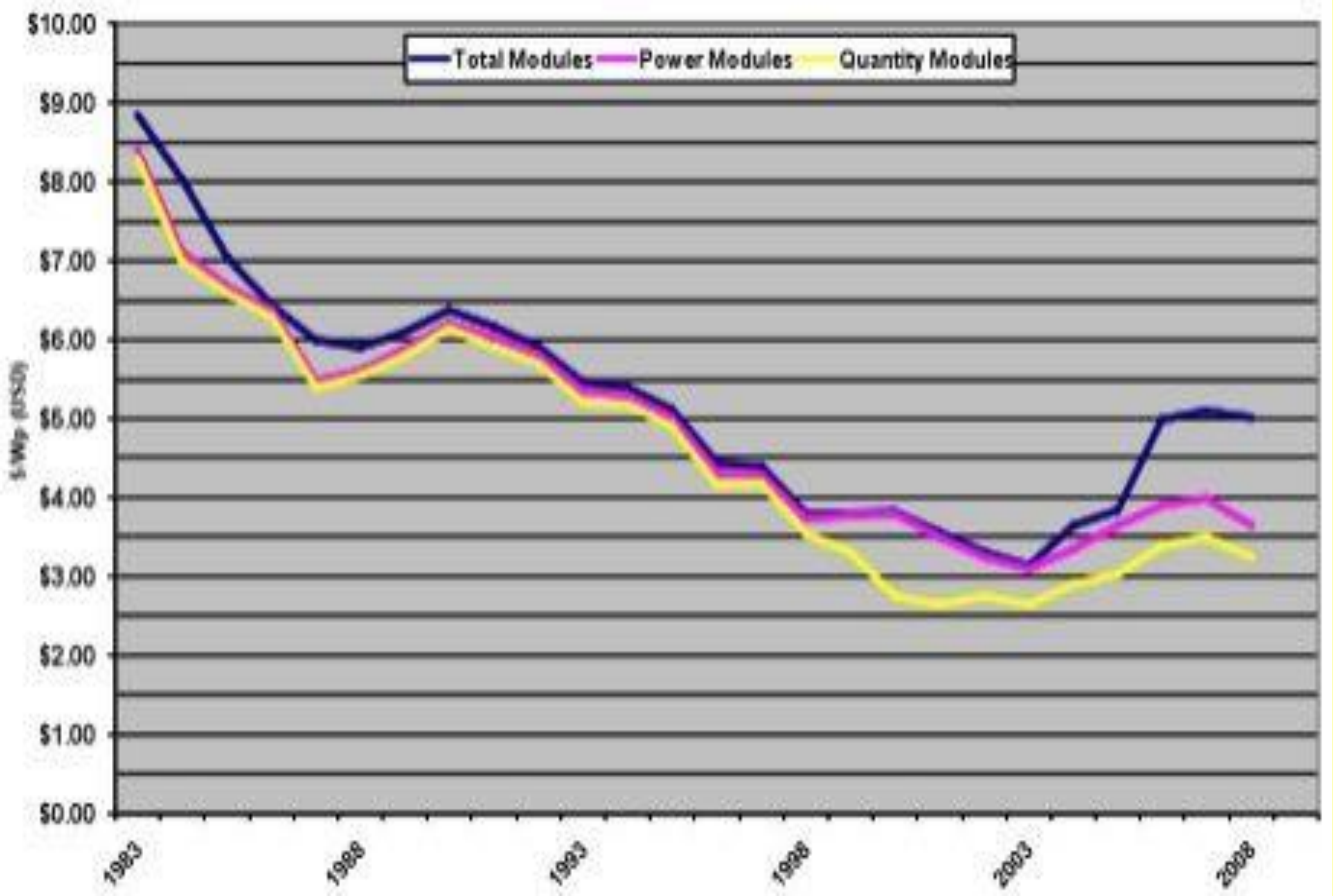
The physical potential of renewable energies



Source: Nitsch F. "Technologische und energiewirtschaftliche Perspektiven erneuerbarer Energien, Deutsches Zentrum für Luft- und Raumfahrt (DLR)", 2007.

Comparison of physical potential of various renewable energy sources
Current annual Global Energy Consumption is added for a comparison

PV Cells – Modules prices,



Average module selling prices, 1983-2008.
(Source: Navigant Consulting

Few basic facts about PV

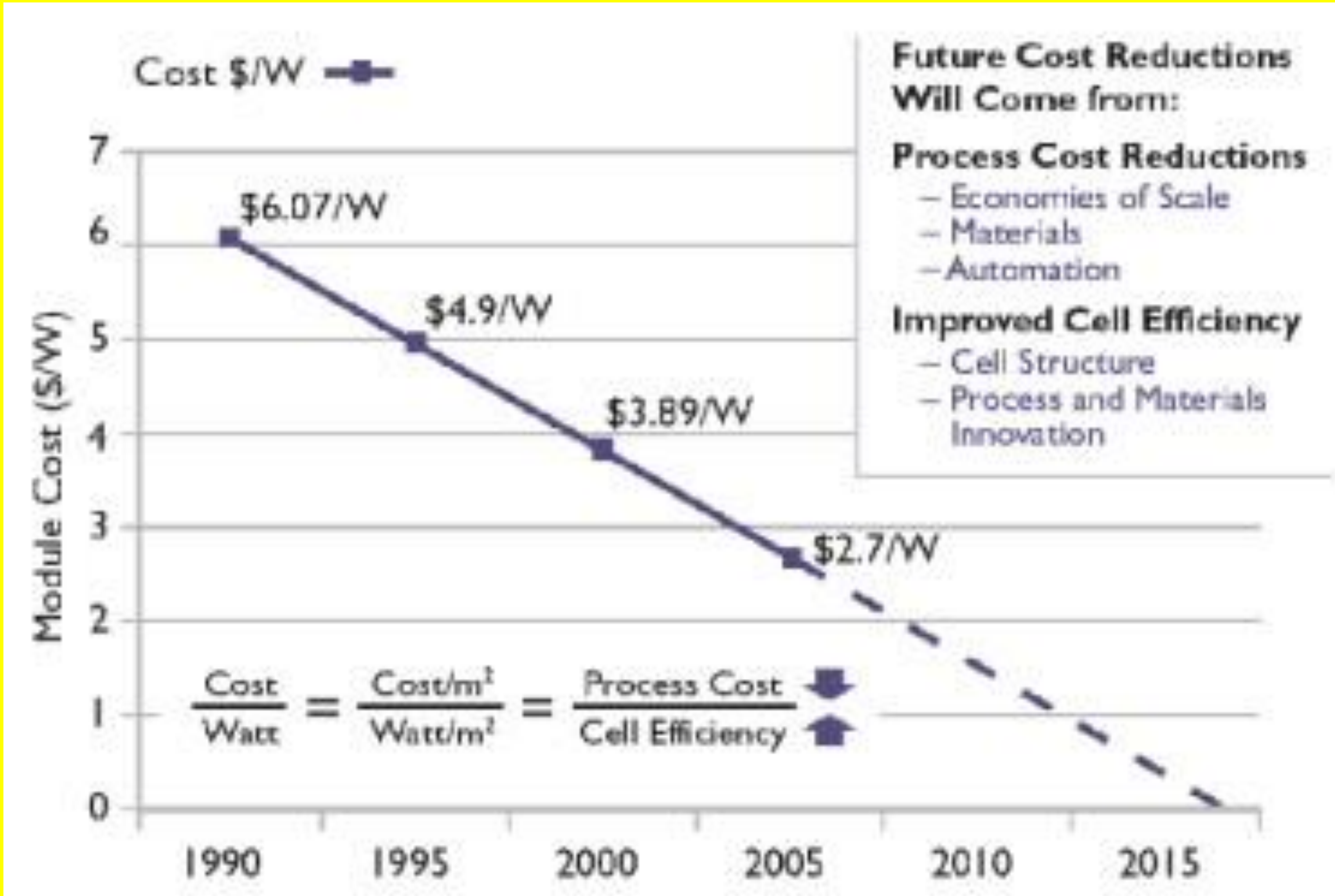
Basic principles of PV were discovered in the 19th century.

Only in 1960s solar cells become used in space (where price was not so important) as electricity generator .

The development benefited grossly from development of early **silicon semiconductor technology** for electronic applications.

Complete PV system is simple and consists of two elements:
a) “modules” (also referred to as “panels”), **which contain solar cells**, and
b) the “Balance-of-System” (“BoS”).
The **BoS** mainly comprises **electronic components, cabling, support structures** and, if applicable, electricity storage or optics & sun trackers.

The PV Learning Curve (more detail for 1990-05 period)



Total Cost reduction cca 2.25x; partly due to decrease of manufacturing cost , partly due to the increase of solar cell efficiency.

Can we separate these two sources?
How much can be expected from both sources of cost reduction in the future?

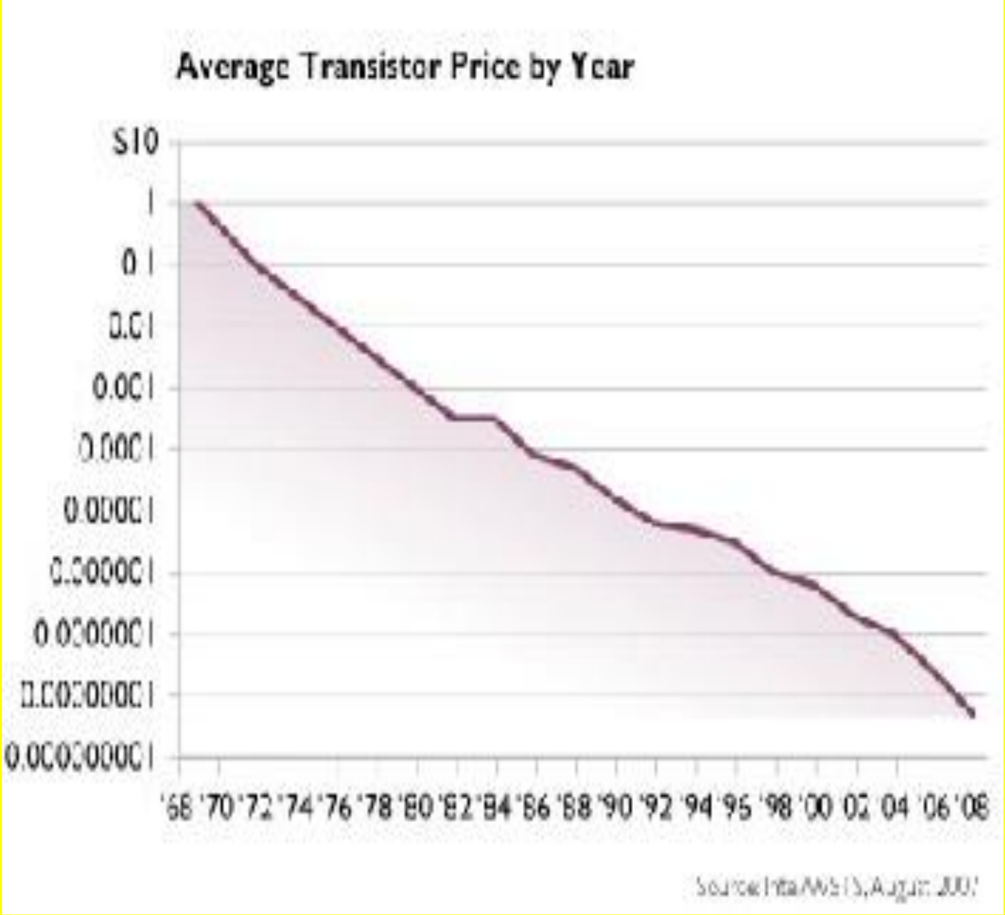
Crystalline Silicon (c-Si)

Si – a fascinating semiconductor, - its technological development enabled all present-day electronics, optoelectronices, etc., and also of c-Si solar cells.

The progress made by semiconductors in cost reduction is one of the technological marvels of our time.
A cumulative cost reduction of 8 orders of magnitude sincey. 1970!

Moors Law: the cost per transistor decreased by factor of 2 every two years.
Most of cost reduction due to reduction of transistor size (8000x) – specific feature of transistor.

However, also chip **manufacturing efficiencies increased since 1975 cca 500X**

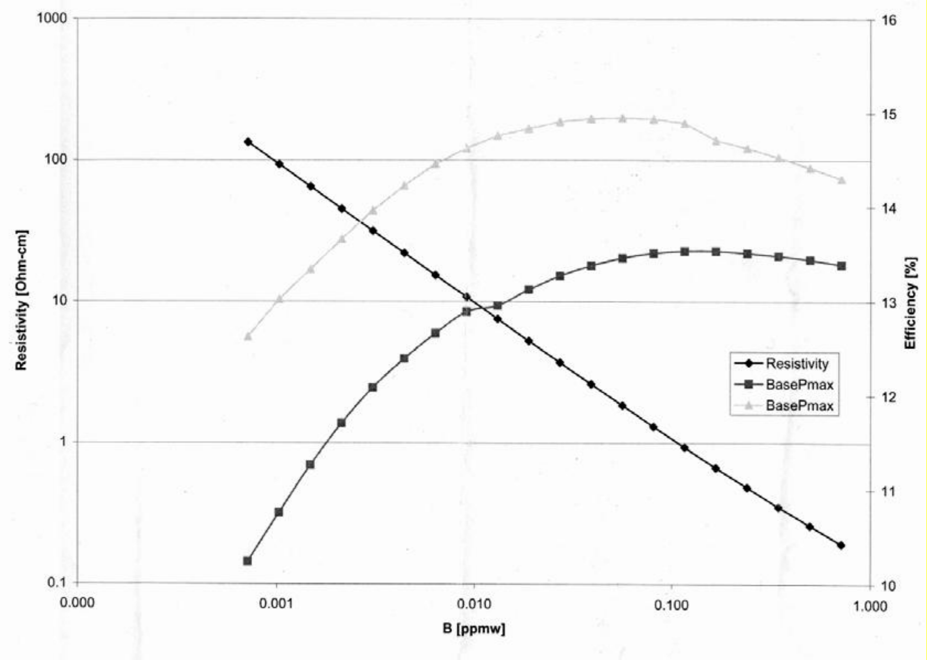


Who were top manufacturers of PV energy in "golden years" 2005 – 2008?

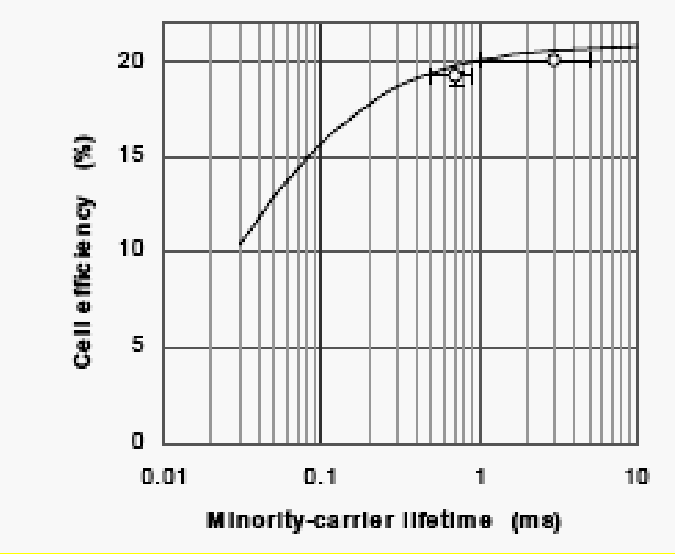
Ranking	2005	2005 MWp	2006	2006 MWp	2007	2007 MWp	2008	2008 MWp	Top Ten 2008 Technology
1	Sharp Solar	375.2	Sharp Solar	434.7	Sharp Solar	363.0	Q-Cells	547.2	c-Si
2	Kyocera	142.0	Q-Cells	240.4	Q-Cells	344.1	Suntech	497.5	c-Si
3	Q-Cells	131.2	Kyocera	180.0	Suntech	309.0	Sharp	458.0	c-Si/a-Si
4	Schott Solar	95.0	Suntech	152.0	Kyocera	207.0	First Solar	434.7	CdTe
5	BP Solar	85.8	Sanyo	120.5	First Solar	186.0	Kyocera	290.0	c-Si
6	Mitsubishi Electric	85.0	Mitsubishi Ele	111.0	Motech	167.0	Motech	263.5	c-Si
7	Sanyo	84.0	Schott Solar	96.0	Sanyo	155.0	Sanyo	220.2	c-Si/a-Si
8	Shell Solar	55.0	Motech	91.8	SolarWorld	136.1	SunPower	215.2	c-Si
9	Motech	45.0	BP Solar	78.0	Mitsubishi Ele	121.0	JA Solar	212.1	c-Si
10	Isofoton	39.3	SunPower	62.7	SunPower	102.0	BP Solar	148.1	c-Si
10a					JA Solar	102.0	Mitsubishi Electric	148.0	c-Si
10b					BP Solar	101.6			
Total Shipments	1407.7		1984.6		3073.0		5491.8		
Above		1137.5		1567.1		2293.8		3434.5	
% Total Shipments		81%		79%		75%		63%	

Source: Navigant Consultants, 2009

Some efficiency losses are influenced by
<u>material properties of specific solar material</u>, c- Si

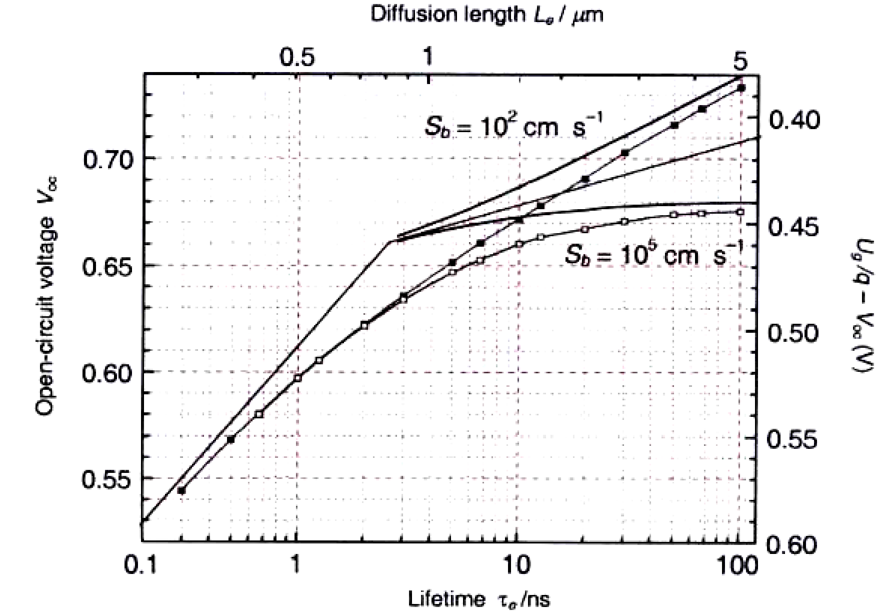


Efficiency dependence on <u>resistivity</u>
(which depends on doping level)

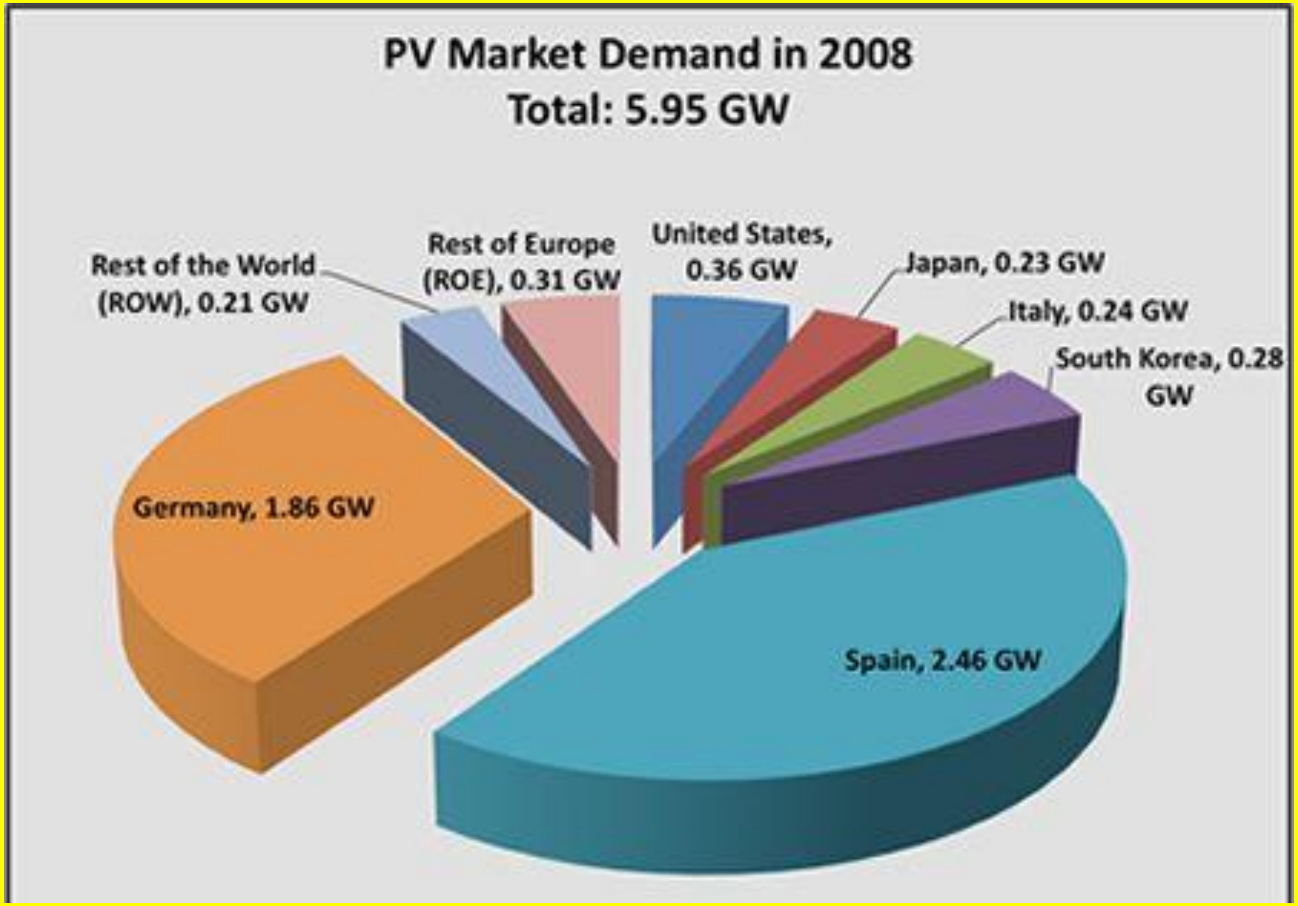


Efficiency dependence on quality of Si material (<u>lifetime of holes</u>)

When <u>lifetime of charge carriers</u> is longer and Surface recombination rate (S) is lower, the <u>Diffusion lenght</u> is longer and Voltage of the cell in higher



World solar PV market doubled to 5.95GW in 2008; Regional Demand

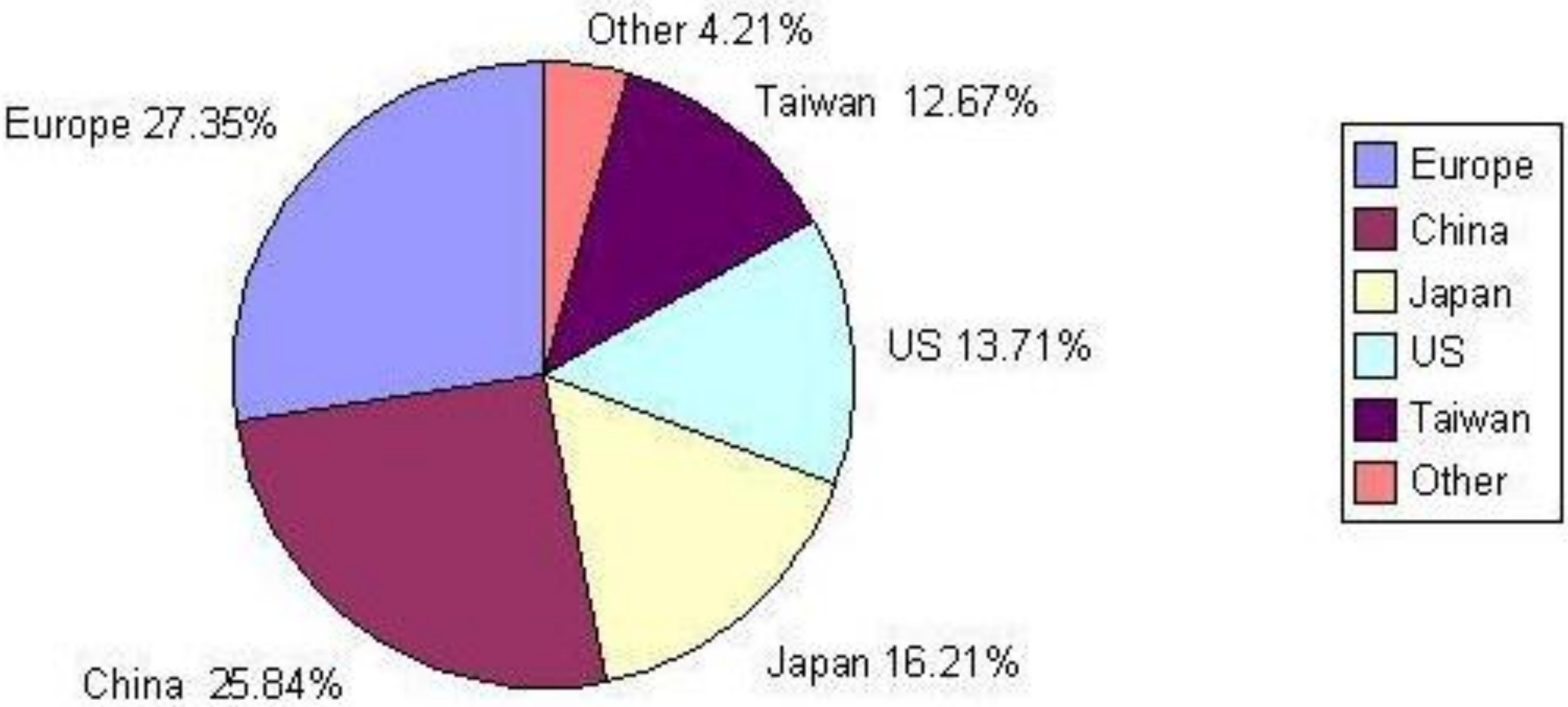


Europe accounted for 82% of world demand in 2008. Spain's 285% growth pushed Germany into second place, while the US advanced to number three. Korea became the fourth largest market, closely followed by Italy and Japan.

In this assessment**, 81 countries** contributed to the 5.95GW world market total.

Source: *Solarbuzz LLC, in PR Newswire* (March, 2009)

Global PV Cell Production in 2008: Regional Ranking



Regional Ranking of Global PV Cell Production in 2008 (Crystalline and Thin Film, Percentage Ranking by Production in Watts).
Source: iSuppli, in Marketbuzz.com

Huge disbalance in country/region of production and of installation of PV modules. As for EU: Result of policy aiming to create jobs and establish a new industry capable of competing on the global stage.

Top 10 solar panel producers for the year 2009. **(total: 10.7 GW)**

First Solar	8.4%
Suntech	8.1%
Sharp	6.8%
Trina Solar	5.3%
Yingli	5.3%
Canadian Solar	5.2%
Solarfun	4.2%
Kyocera	4.1%
Sunpower	3.4%
Sanyo	3.0%
Others	*46.2%*

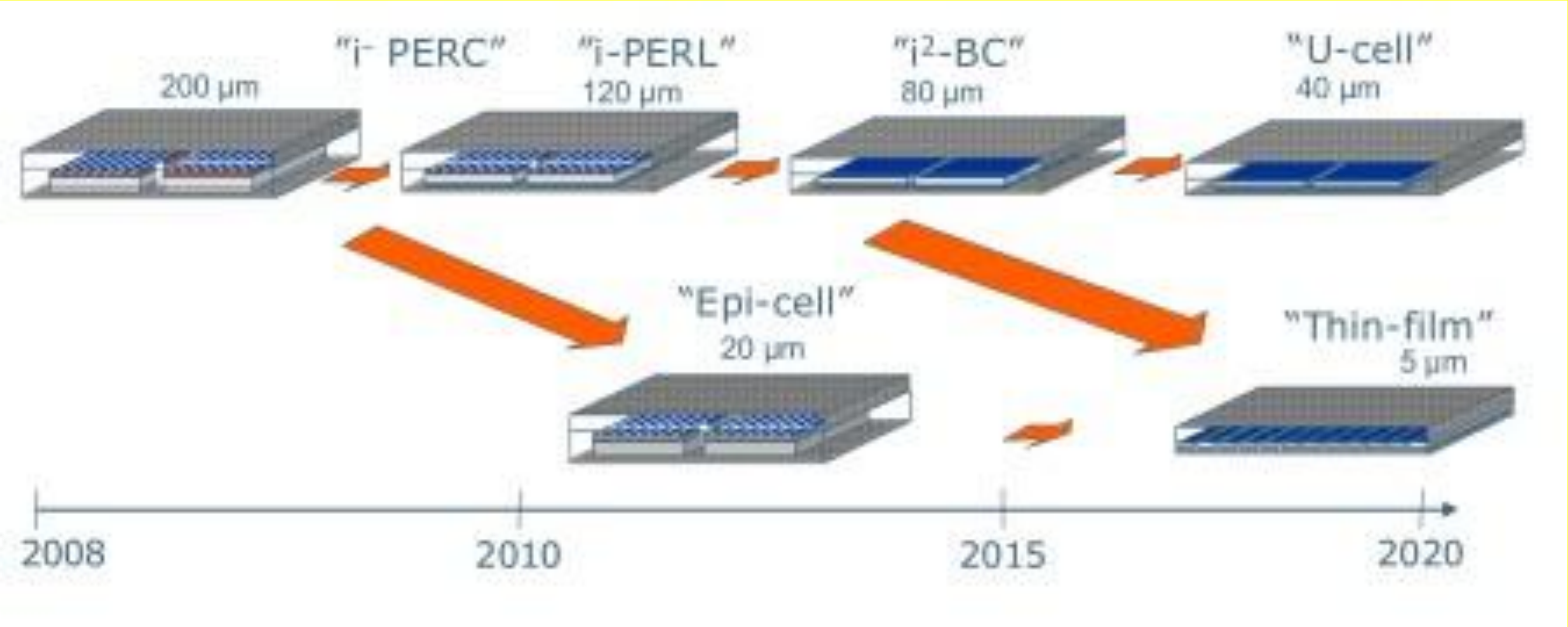
Source: http://www.electroiq.com/

Thin Si solar cells:

From the proposed a roadmap for **thin c-Si solar cells incorporating IC-like technologies and methodologies**.

Such roadmaps have become an established means in the IC industry for enhanced collaboration between manufacturers, equipment vendors, and material suppliers.

The PV industry is in many respects quite different from the IC industry, but the **potential R&D synergies may be equally instrumental to the PV industry**



Top 10 solar cell producers for the year 2005. Total: 1.4 GW)

Manu-facturer	Produ ct,MW	Market share (%)
Sharp	428	**24.8%**, Mono- and poly-crystalline Si (mc % pc Si)
Q-Cells	160	**9.5 %**, pc/a-Si hybrd
Kyocera	142	**8.2 %**, pc. Si
Sanyo	125	7.2%, pc. Si
Mitsubishi	100	5.8%, a-Si thin f.
Schott Solar	95	5.5%, mc, pc, a-Si
BP Solar	90	5.2 %, mc, pc Si
Suntech	80	4.6 %, mc Si
Motech	60	3.5 % pc Si
Shell Solar	59	3.4 %, mc, pc Si, CIS
Others		Mostly mc or pc Si

Oct. 2006, R&D reports, SC Manufacturers

Top 10 solar cell producers for the year 2009. . (total: 8.9 GW)

1. **First Solar (U.S.) (Thin film, CdTe)**
2. Suntech Power (China)
3. Sharp (Japan)
4. Q-Cells (Germany)
5. Yingli Green Energy (China)
6. JA Solar (China)
7. Kyocera (Japan)
8. Trina Solar (China)
9. SunPower (U.S.)
10. Gintech (Taiwan)

Polly/mono Crystalline Slicon total: 78%
Thin film (CdTe, a-Si. CIGS) total: 22%

Source: http://www.electroiq.com/

REDUCING PRICE OF PV ELECTRICITY:

Accelerated bifurcation in manufacturing approaches

The first example assumes the underlying trend of the past couple of years gathers stronger momentum: the move to either low-cost manufacturing (exemplified by c-Si cell making in Taiwan and China and thin-film panels by First Solar) or high-efficiency cell production (average efficiencies in volume production above 17%). Consequently, production would be dominated by a select group (<10) of cell makers -- all manufacturing in the Asia-Pacific -- who account for >90% market share. (In 2009, around 30 companies accounted for 90% of production output).

Supply-chain drives technology, spearheaded by turnkey lines

In this scenario, production from turnkey lines explodes during 2011-2013. Existing turnkey lines (both c-Si and thin-film) are ramped up with high utilization rates and low cost structures. Production from turnkey lines moves from ~11% of worldwide output in 2009 to >50% by 2013, and turnkey custodians emerge with repeat orders for capacity expansion. High-efficiency c-Si turnkey lines make an immediate impact with cell producers, as the different selective emitter approaches each demonstrate significant cost-benefit advantages. Existing c-Si turnkey lines are upgraded to high efficiency by the equipment suppliers. All a:Si turnkey lines operate with multi-junction layers and high efficiency.

Source:Paper by F.. Colville, Coherent Inc, Maech 2010

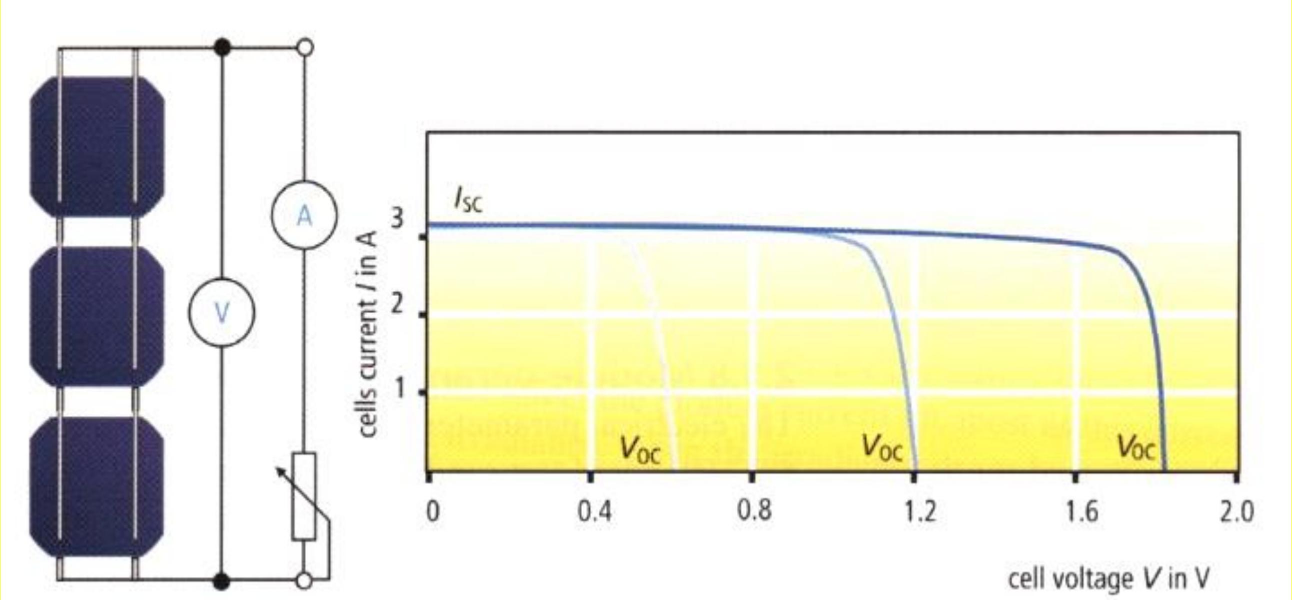
REDUCING PRICE OF PV ELECTRICITY:

Building Integrated Photovoltaic (BIPV) modules

Advocates say BIPV technology could dramatically cut costs of manufacturing and installing solar power and could expand the solar market. The BIPV market in Europe, the biggest market for the technology, grew 43.8 percent last year to reach €142.6 million [US $186.4 million], according to an October report from research firm Frost & Sullivan, which predicted that the "explosive growth rate" would continue.

Another research firm, NanoMarkets, has forecast that the BIPV market will make up about US $800 million in 2011, exceed US $4 billion in global revenues by 2013 and surpass US $8 billion in 2015. While most BIPV products today are based on traditional crystalline silicon, with companies such as Sharp, Kyocera, General Electric, BP Solar, SunPower and Suntech Power involved in roofing tiles, advocates say that thin-film materials could revolutionize the market, enabling differently shaped products for new applications that crystalline panels can't address and potentially reducing building costs.

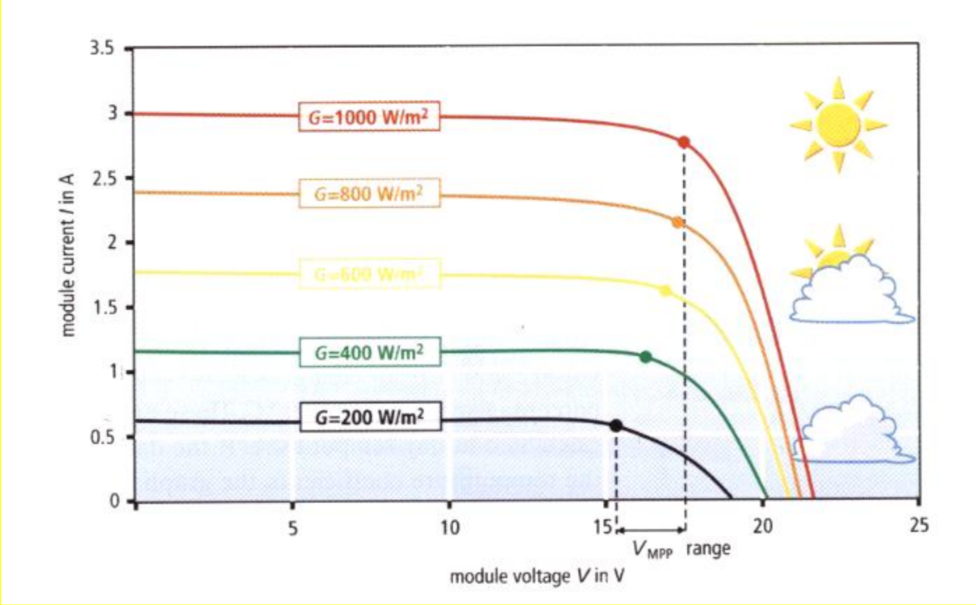
PV Solar cells are wired into solar modules



String of 3, 6-in x 6-in GE solar cells (3.4W each)

GE 130W Module (4x9 strings)

Serial connection** of Cells in Module: **larger Voltage
Parallel connection** of Cells in Module: **larger Current



Cell and Module current is also strongly dependent on light intensity (Cell Voltage is almost insensitive)

ACCELERATING IMPLEMENTATION OF PV:

Incentives, Fiscal and/or Political Mesures, …..

Saving Money and the Planet

The 540 solar systems that Sungevity has sold since the lease program's inception on March 1st will generate 4,343,000 kWh of clean energy each year. This will save the newest group of Sungevity customers over $1 million per year on utility bills, which equates to a savings of roughly $25 million over the expected life of the solar systems.

The environment also benefits - Sungevity and its customers are removing 130,547,254 pounds of carbon from the atmosphere each year, which is equivalent to taking 212,413,403 cars off the road or planting 386,939 trees each year.

Is there enough cadmium for large-scale CdTe PV?

Large-scale (i.e., GW/year) production of CdTe PV would require less than 3% of the current Cd consumption.

Using less than 1/3 of the current Cd consumption for PV would change US electricity infrastructure in only a few years.
To change the world's energy infrastructure with CdTe PV, much less Cd would be needed than is already used for other purposes.
It might not even impact the overall smelting of Cd at all!

Currently, Cd is obtained as by-product in processing ore to obtain some other metals (Zn, Sb). The surplus Cd is often cemented , ending-up in a waste dump!

Presently, most Cd is used in NiCd rechargeable batteries (~65%), paint pigments (~17%), plastic stabilizers (~10%), metal plating (~5%), and metal solders (~2%).

Does the compound CdTe pose the same health risk as elemental Cd?

CdTe is more stable and less soluble than elemental Cd and therefore is likely to be much less toxic. However, more long-term data are needed to¸firmly confirm it.

The Learning Curve for PV :

Cost reduction in 1990-2005 period :

Part due to the **increase of solar cell efficiency** : at least **20 %.**

part due to **decrease of manufacturing costs**: **2.25/1.20 = 1.85**

Hence, cost reduction due to **decrease of manufacturing costs** (economies of scale, plus learning and process improvements) **contributed less than 2x to the total cost reduction of PV modules**

This is **much less than achievements of semiconductor industry** in increasing manufacturing efficiency (**500x**).

Hence, **there is huge potential for reduction of costs in the PV industry**, based on the comparable experience of the semiconductor industry.

The **semiconductor industry is a highly organized supply-chain with clear industry standards, technology roadmaps and highly evolved customer-supplier collaboration** mechanisms. PV industry is still far away of becoming similarly well organized

PV as a potential resource for electricity generation

The solar energy resource is larger than all other renewable energy resources. Its potential is larger than potential of all non-renewable and renewable sources together.

In a realistic (but ambitious) scenario, PV can covers 20% of global electricity consumption by 2040.

Already in 2020 PV may contribute to the reduction of CO2-emissions by the equivalent of 75 average-sized coal-fired power plants or 45 million cars [EPI 2004].

Since PV is well deployable also *within Europe, it* can play an important role in improving the security of Europe's energy supply.

Moreover, PV is very well suited to providing access to energy in rural areas, thus enabling improved healthcare and education and providing economic opportunities both in EU's less developed parts as well more widely, in undeveloped/developing countries.

Specifically, it may bring electricity to hundreds of millions people in developing countries by 2020 to 2030.

Years 2004-2008:

F**rom 2004 to 2008** shipments grew by a compound **annual rate of 51%**.

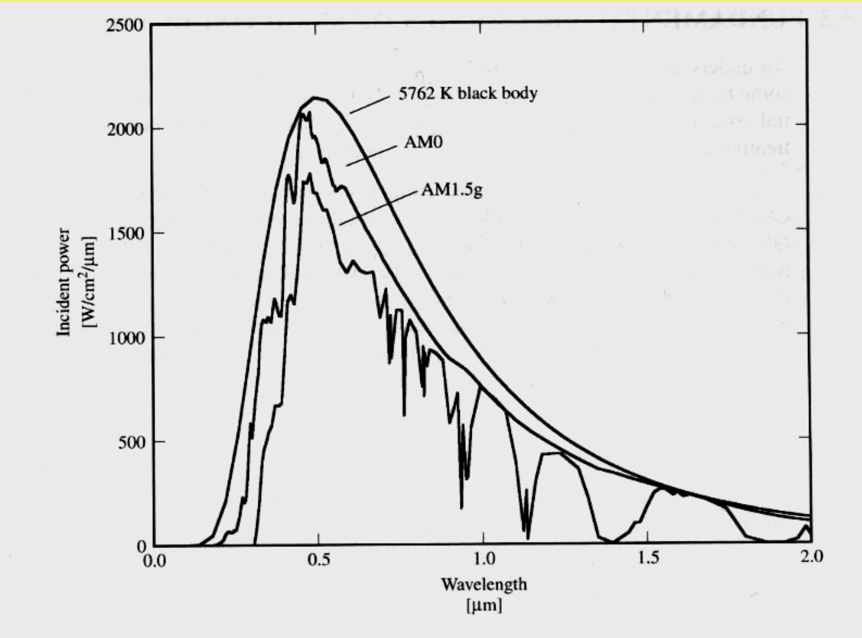
The year 2000 began with Germany passing its renewable energy law, which established the first feed-in tariff and set the stage for the most profitable and highest growth decade in the 35 year history of the terrestrial solar industry.

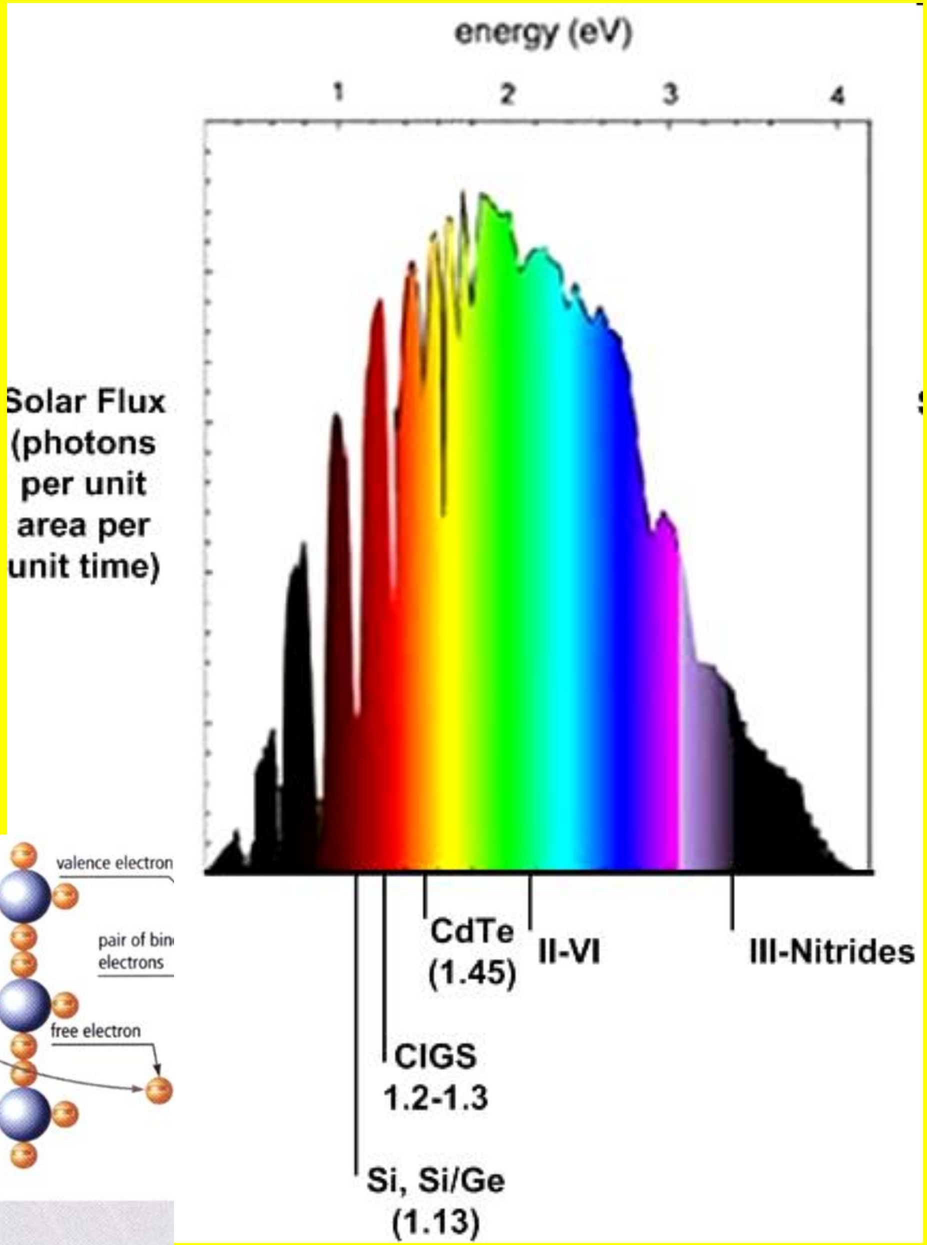
At the end of 2009, a cumulative 20.6 GW had been sold into the market – 95% of this, or 19.6 GW, in the last 10 years, mostly into grid-connected application.

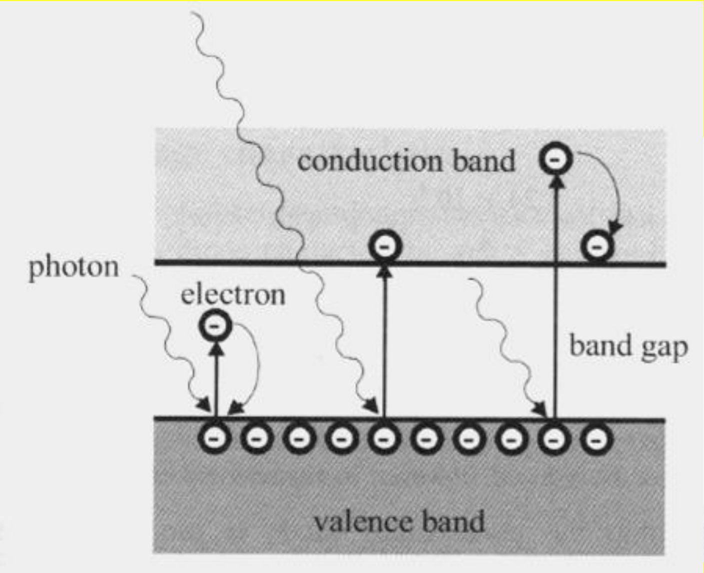
Buying cells and modules during the 2004–2008 period was a wild ride, with strong demand **driving prices up as much as 30%** in some cases for all technologies.

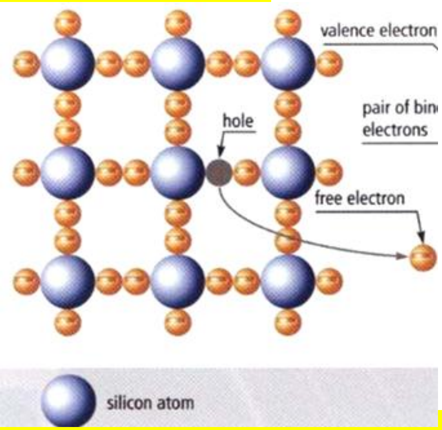
Meanwhile, other countries in Europe instituted feed-in tariffs and demand began to spread out from Germany, particularly to Spain

Solar Spectrum









Band-gap is related to energy needed to disrupt crystal lattice bonds and free an electron

Band-gaps of some solar cell materials in relation with solar spectrum

In y. 2003-2005 PV cell/module price stopped falling after over 4 decades of falling by 'learning curve'

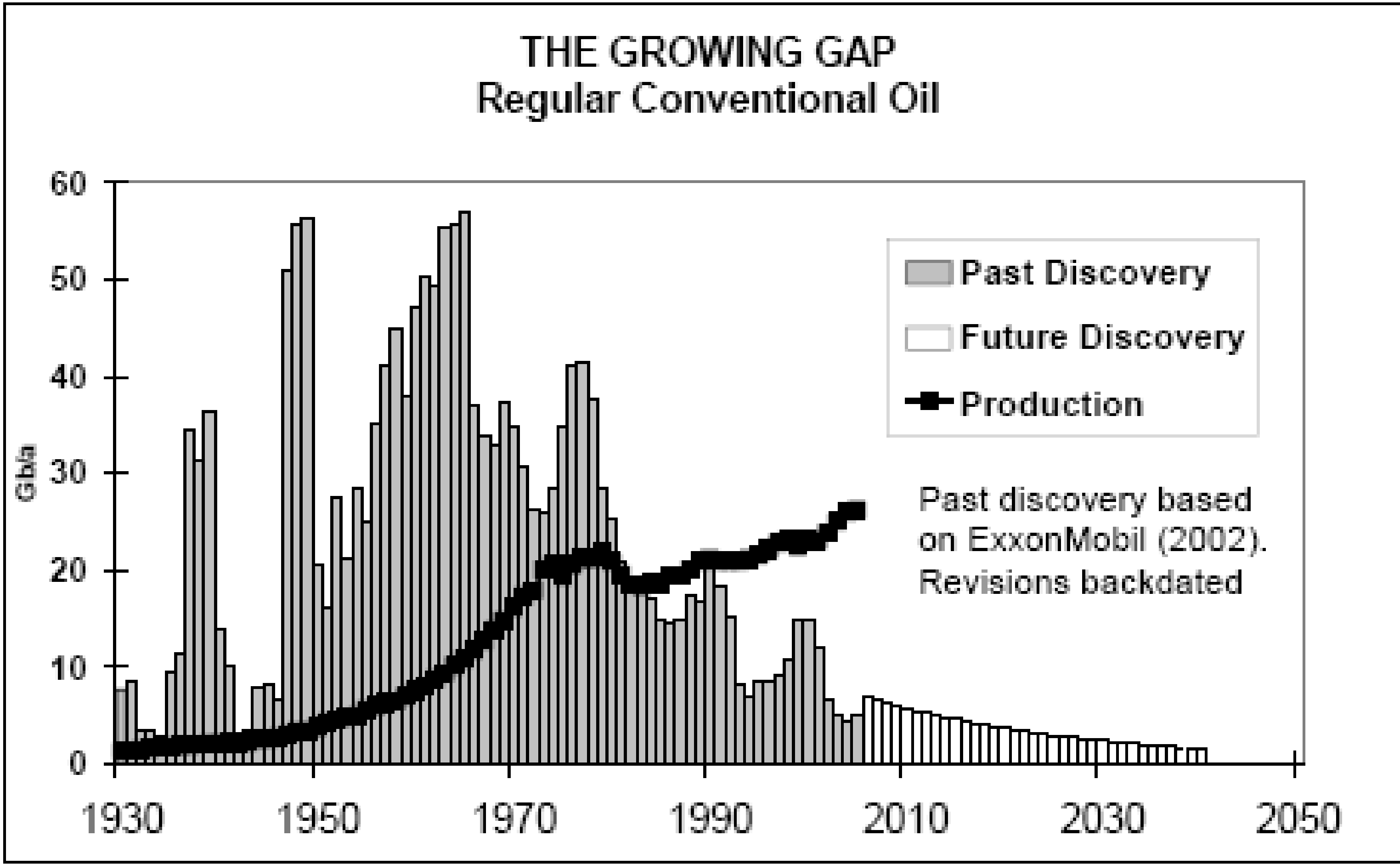
Main causes:

-**Production/installation of PV modules increased by unprecedented pace**

-**Undersupply of (solar-grade) Silicon occurred. Silicon price has risen from $28/Kg to more >$400/Kg!**

(After economic crash in 2009 the Si price was down to $50/Kg!)

-**Altogether, PV was a (temporary) victim of its own enormous success!!**


THE GROWING GAP
Regular Conventional Oil
60
50
40
30
20
10
0
Gb/a
1930
1950
1970
1990
2010
2030
2050
Past Discovery
Future Discovery
Production
Past discovery based on ExxonMobil (2002). Revisions backdated

PV Eco-communities

Standardized, multifunctional building components make eco-communities possible

Everyone Benefits

Architects:
Can easily spec. energy system from widely available commercial products

Contractors/Developers:
Easily installable integrated building products. Can claim tax credits and has unique discriminator for homes

Consumer:
Quality installation of technologies that provide long-term benefits.

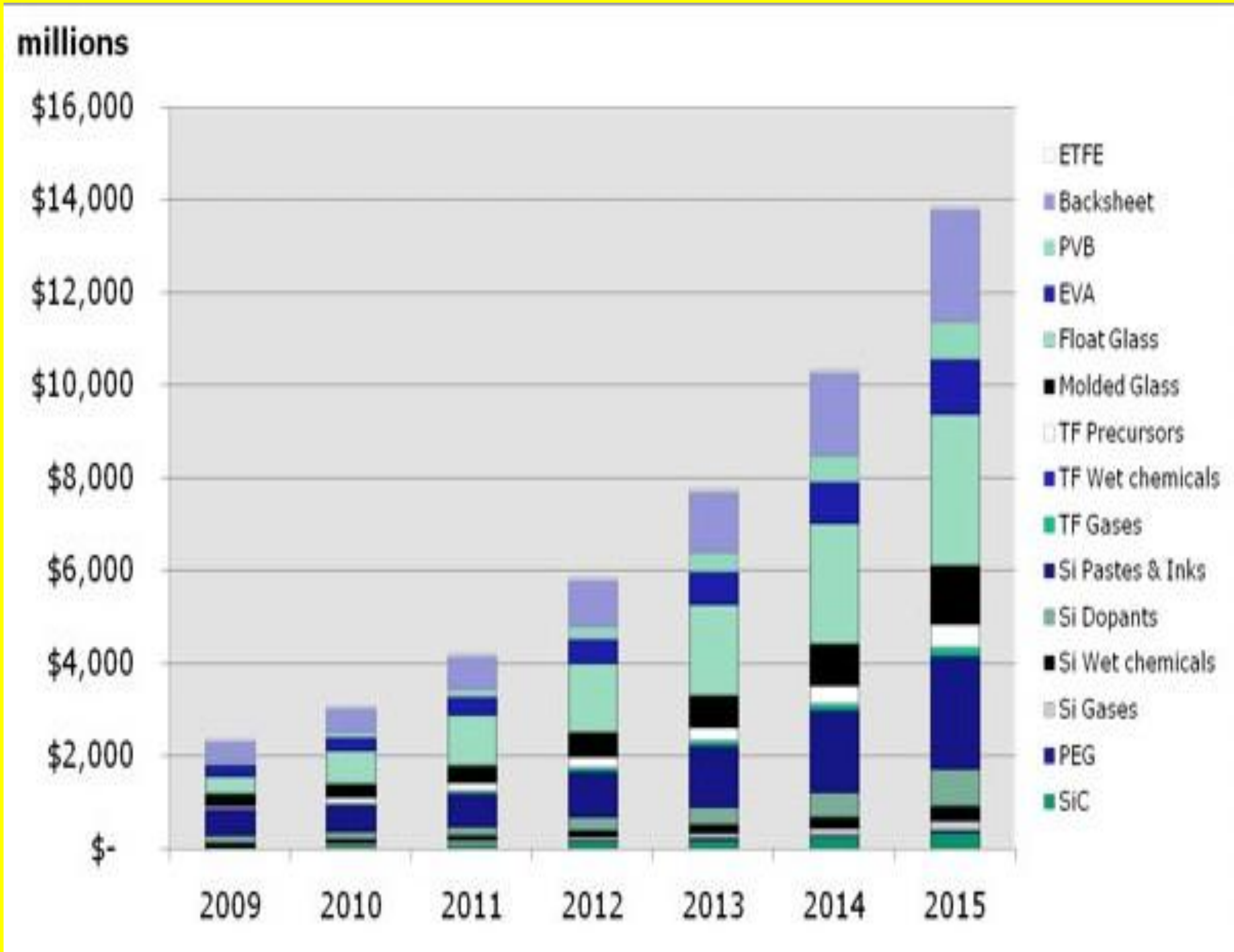
Government:
Wide proliferation of technologies that have lasting positive impact on energy use/security
Lower energy import

PV – FUTURE PROGNOSES
- PV materials

Feb 25, 2010: Analyst: PV materials seeing 27% growth in 2010.

Advanced chemicals and materials used to make PV solar cells and modules continue to establish a foothold, poised to grow to about $14B by 2015, according to an industry analyst.

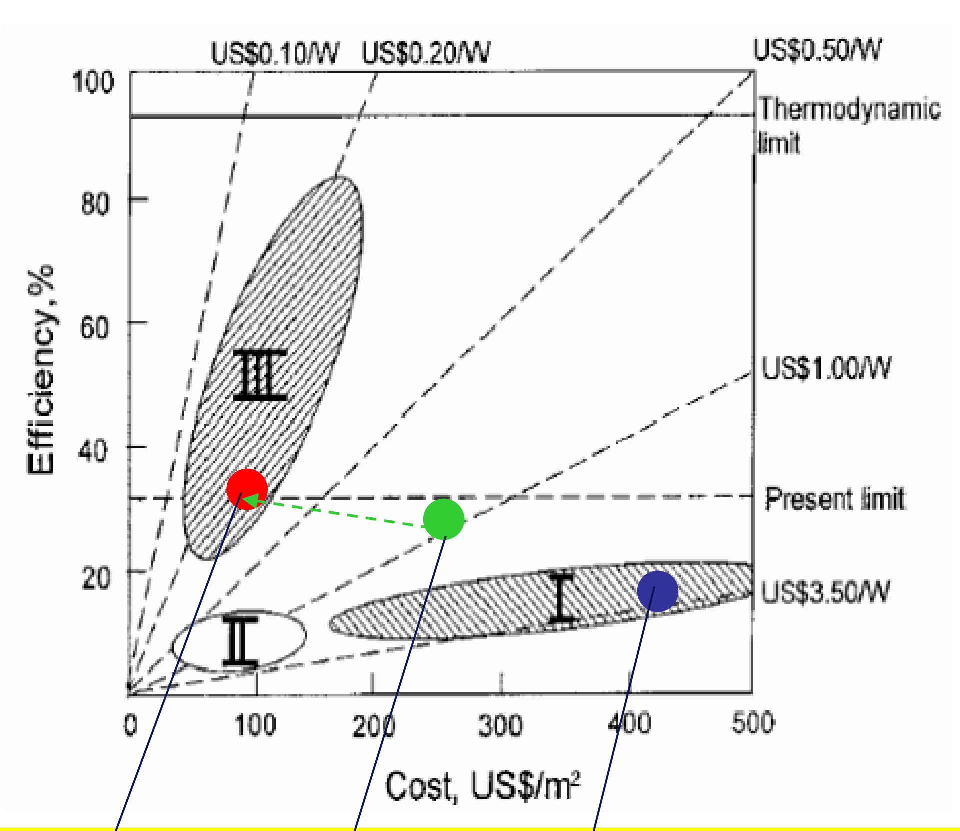
The market for PV chemicals and materials declined slightly to around $2.44B in 2009, and should grow 27% to $3.1B in 2010, and step along to a $14B tally within the next six years, forecasts Linx Consulting. Driving this growth will be end-market demand for solar power, expected to push from 5.8GW to 38GW during the same timeframe.



Total PV materials market. (Source: Linx-AEI Consulting)

The Three Generations of PV

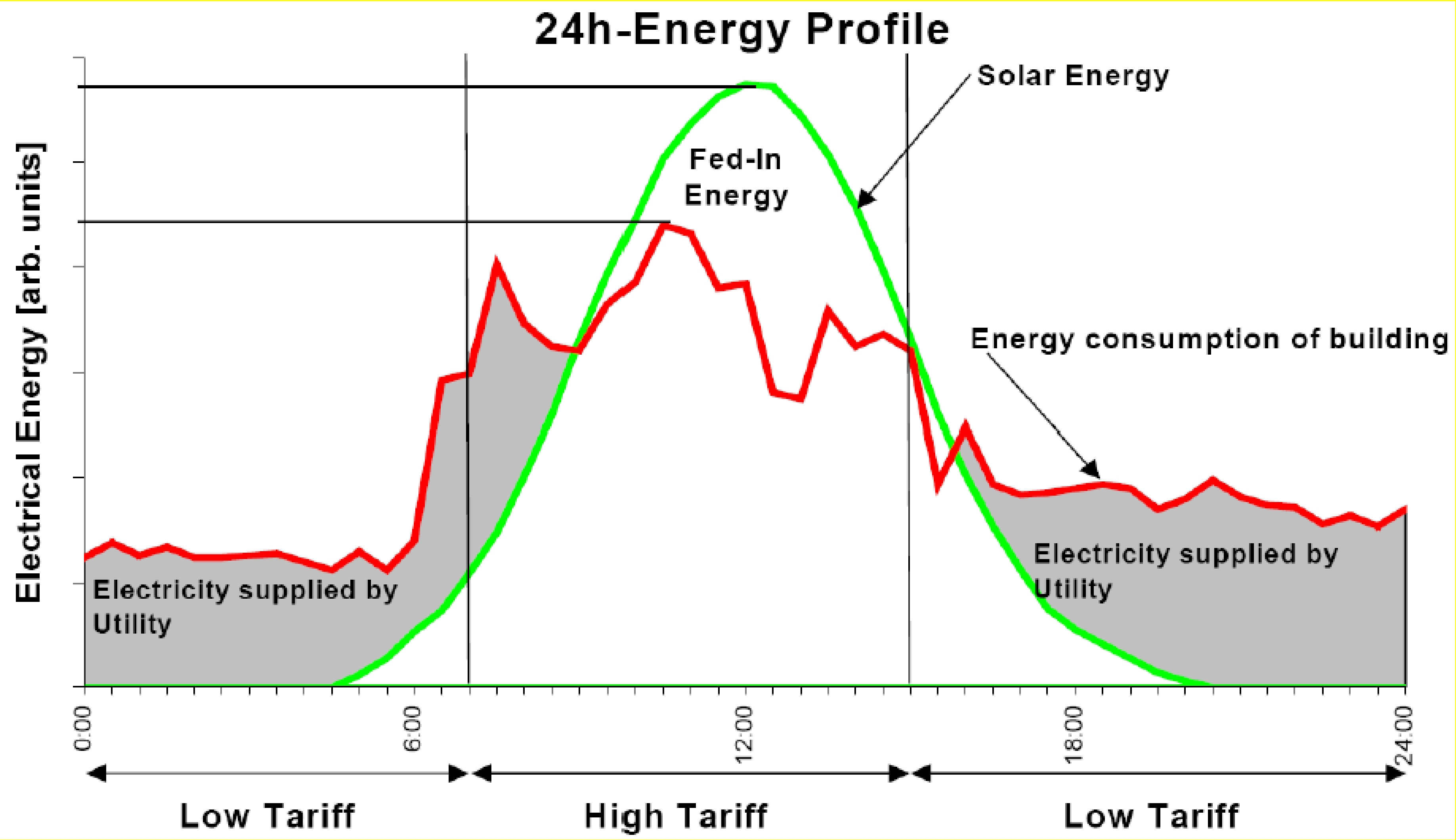
- **First Generation**
  - ➔ Crystalline and poly-crystalline Si
  - ➔ ~15% efficiency, ~ \$3/W_p
- **Second Generation**
  - ➔ Thin film cells CdTe, $CuInSe_2$
  - ➔ (10-15)% effic., ~ \$(1-2)/W_p
- **Third Generation**
  - ➔ expensive - III-V cells
  - ➔ (400-1000)x concentration for large scale power < \$1/W_p.



Our Target (1000x)

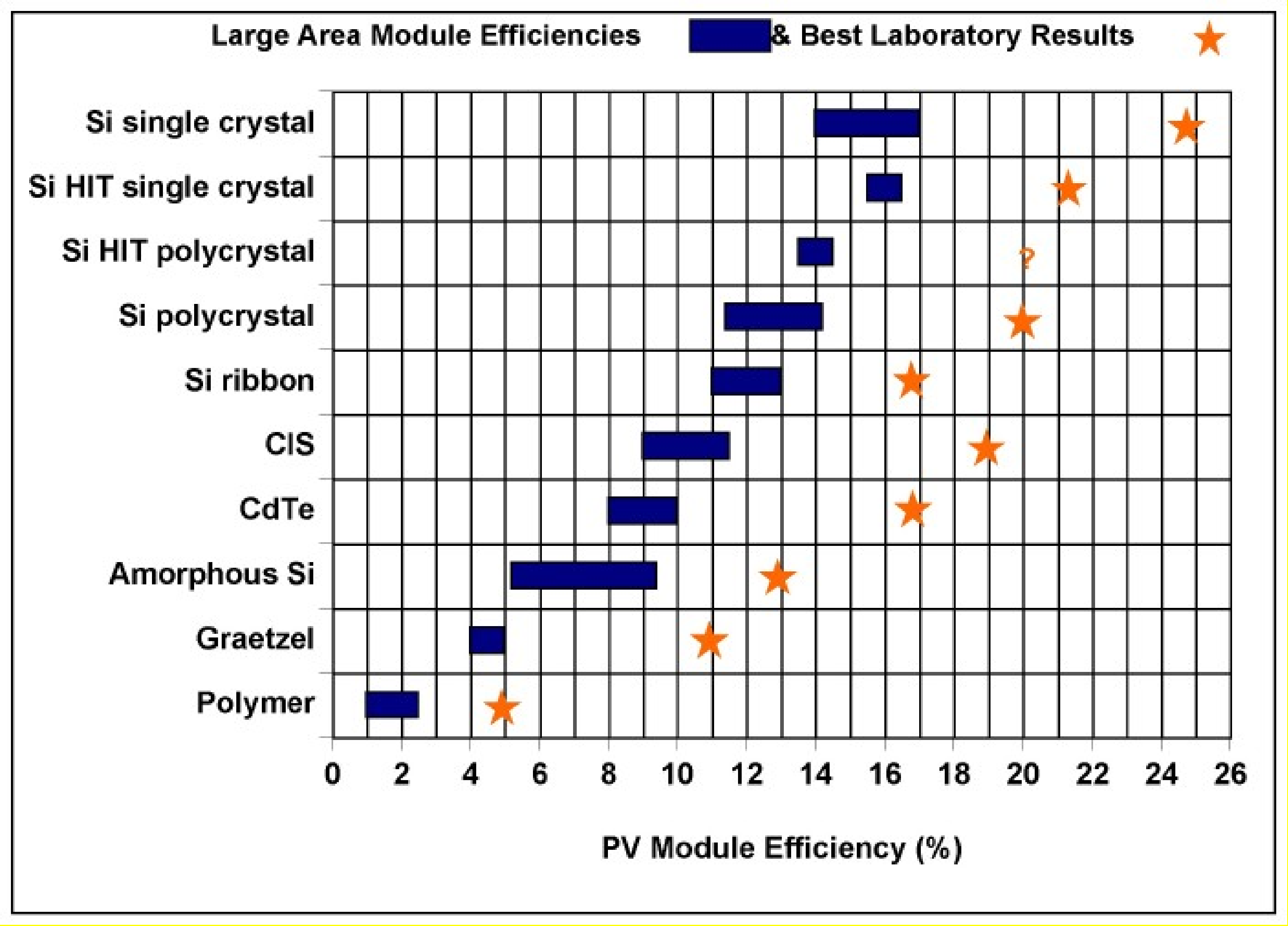
Our Present State (200x)

Silicon - no concentration



"Peak power at peak hours"

Efficiency of commertial solar cells – on large scale and laboratory results



The Increase of Solar Cell efficiency

Cell Efficiency (in %) Improvements From 1990-2005

•Single Crystal Si	20 to 24%	(20.0% gain in 15 y.)
•Multi-Crystal Si	16 to 18%	(12.5% gain in 15 y.)
•Amorphous Si	8 to 12 %	(50.0% gain in 15 y.)
•CdTe	12-16 %	(33.3% gain in 15 y.)

•Source: NREL

In 1990-2005 period, the average increase of cell efficiency accros 4 leading tehnologies was about 20- 25 %.

PLACE OF PV in SATSFYING ENERGY /ELECTRICITY NEEDS

WIND AND SOLAR POWER Global nameplate capacity of wind powered generation of electricity was 122 Gigawatts in 2008 [4]. But taking into efficiency, the production was about 1.5 % of world wide usage. It has doubled between 2005 -2008. Solar photovoltaic power is under intense research and development for higher conversion efficiency and lower production costs.

According to Concentrated Solar Power (CSP) [5] the world could satisfy 3% of global demand by 2030 with a combined solar powered capacity of over 830 Gigawatts by 2050.

However, time is needed until 2020 to increase conversion efficiency from present 10% to 14% and to reduce installed system cost from the present value of about $4000/kW to, or below $1200/kW. So even in this optimistic vision of solar future there would not be a significant contribution to the renewable energy production before 2030. T

he Obama government has ambitious plans for renewable energy, which is 10% by 2012 and 25% by 2025 [6].

The EU has similar plan of up to 20% for wind energy and 15% for solar energy by 2020 [7].

The UK government has set an ambitious target for generating 30% of electricity by renewable sources by 2020 Whether these targets are achievable remains to be seen. Looking into the near future of next 10 years, it is clear that renewable energy sources can only supply 10-20% of our energy needs [2]. The rest has to come from the baseload.

Croatia: RES POTENTIALS (RE SOURCES):

Analized in **National energy Programs – NEP y. 1997**
(SUNEN for solar energy, EWIND for wind energy, COGEN for cogeneration....)

Solar: According to the SUNEN National Energy Program, the total economical potential of solar energy is cca 100 PJ (28 TWh).

Wind: Some Croatian islands and part of the Adriatic coast are good potential site locations for wind energy. According to the ENWIND National Energy Program the total energy potential of wind is: 209 MW on the islands, and 163 MW on the Coast

Biomass: In 2001, bio-energy accounted for 3.3% of the total energy supply of Croatia and the total energy potential of biomass is 39 PJ.

Small hydro: The total potential energy capacity of small hydro sources is 177 MW.

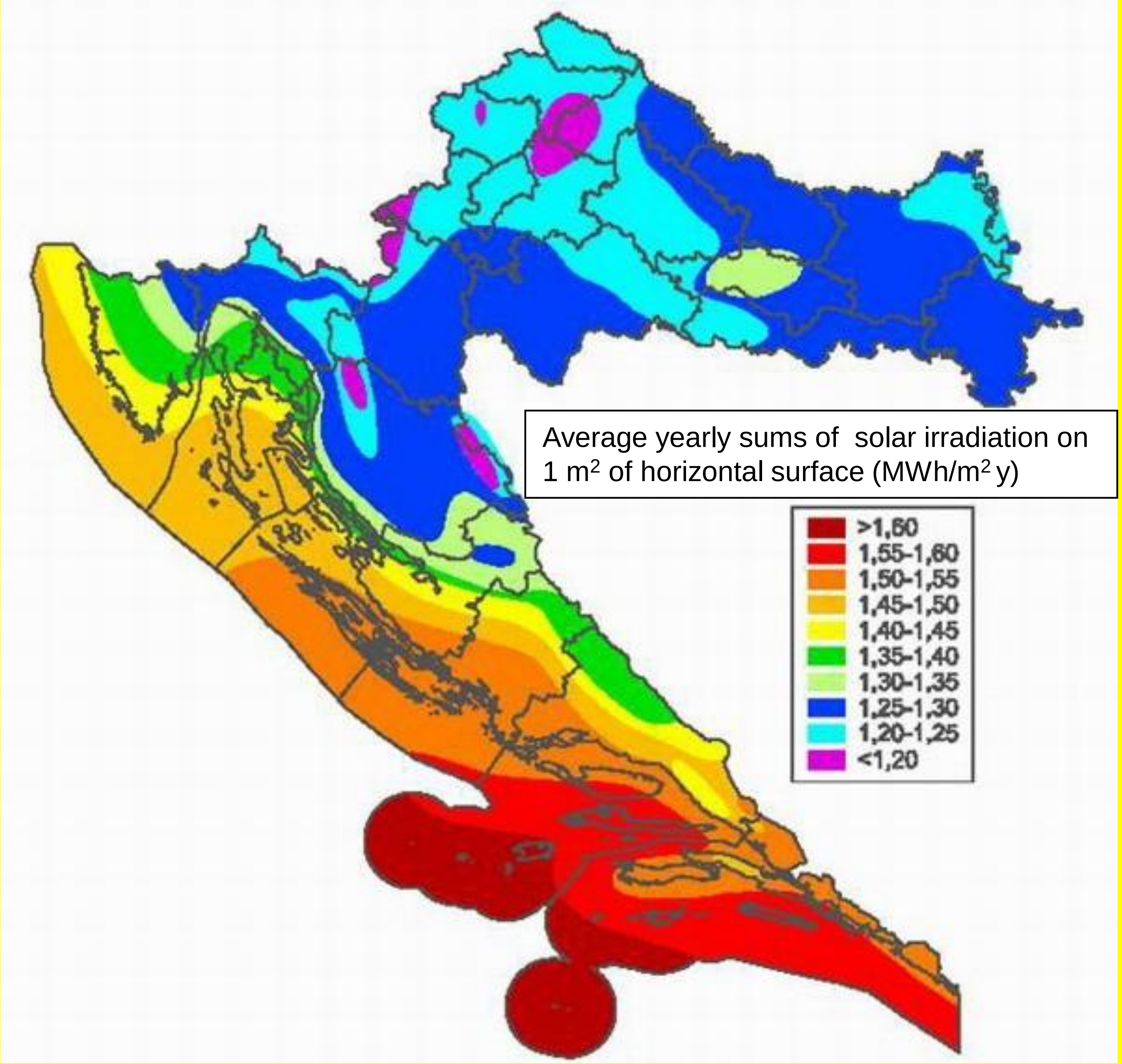
Geothermal: Some geothermal reservoirs in the northern part of Croatia. Total potential estimated at 839 MW_t , installed : 36.7 MW_t).

CONSIDERABLE POTENTIAL FOR MANY RES

BUT LITTLE REALY HAPPENED!

PANEL SESSION: RES: Investments and Regulatory Framework in the Balkans

SOLAR ENERGY



CROATIA: Average yearly sums of solar irradiation on each m^2 of horizontal surface

U. Desnica, I. Raguzin
6th BPC, Ohrid June 2, 2006

Croatia presently utilizes much less of solar energy than many EU countries with less sun

location/region	yearly average, kWh/m^2 day	July, kWh/m^2 day	January, kWh/m^2 day
Dubrovnik (coast, south)	4.4	7.0	1.8
Split (coast, middle part)	4.2	6.6	1.7
Istra (coast, northern part)	3.4	6.0	1.2
Slavonija (inlands)	3.4	6.0	1.0
Zagreb (inlands, city)	3.2	5.7	0.9-1.0
northern Europe (The Nederland, Denmark, U.K., south of Sweden)	2.6-3.0	5,0-5,6	0.4-0.5
mid Europe, (most of Germany& France etc)	3.0-3.2	5.2-5.8	0.5-1.0
south of Europe (south of Greece, of Spain....)	4.4-4.8	7.2-7.6	1.8-2.6

A comparison of daily global solar radiation (10-y. averages) at horizontal planes for different parts of Croatia and EU.

In the procedure for acceptance:

Secondary legislation (by-laws) RES (2)

– Tariff System for Electricity Production from RES and Cogeneration
  - Working version:..

Type of RES	C (HRK)
PV plants, up to 30 kW	3,25
PV, above 30 kW	2,95
Hydroplants	0,73
windplants	0,59
plants on biomass	0,51
geothermal plants	0,66
plants on biogas and liquid bio	0,88
biogas from wastewater treatment	0,22
combination of the above	0,60
other RES (see waves, tides etc.	0,60

1 EURO = 7.3 HRK