Solar Photovoltaics and their applications

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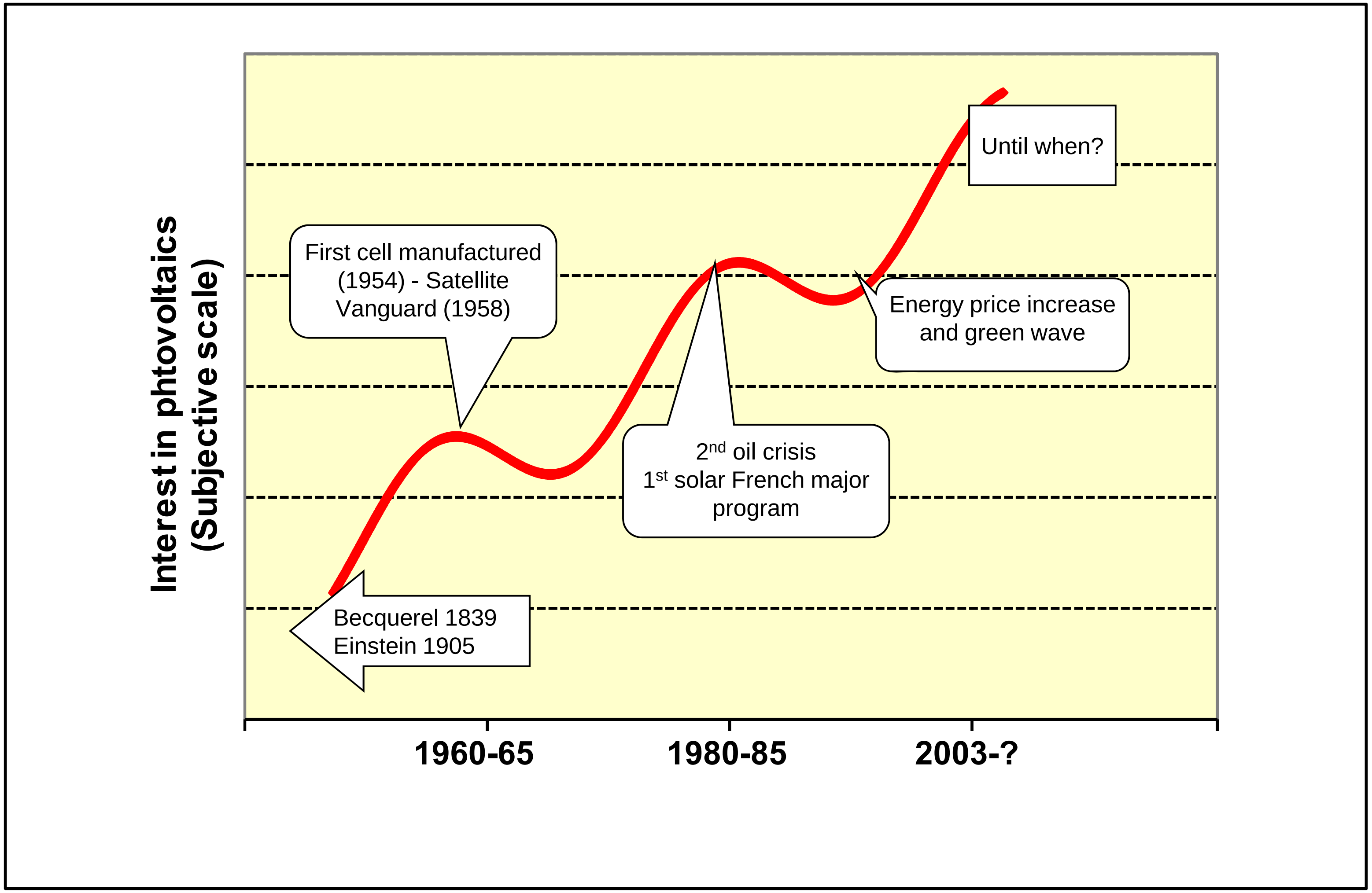
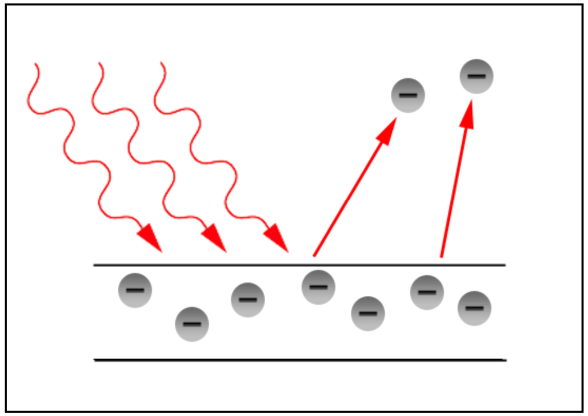
Photovoltaics : Oscillating between enthusiasm and deception

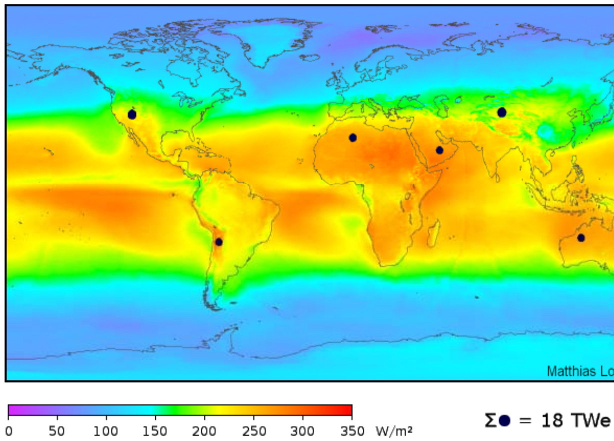


Phtovoltaics: an attractive technology

- Direct and static conversion of solar energy
- Totally renewable
- Relying on one of the most abundant material : Silica
- Non CO_2 emitting (after initial investment)
- Considered as non polluting
- Modular, accessible everywhere and free of charge



Photovoltaic effect



Solar world atlas

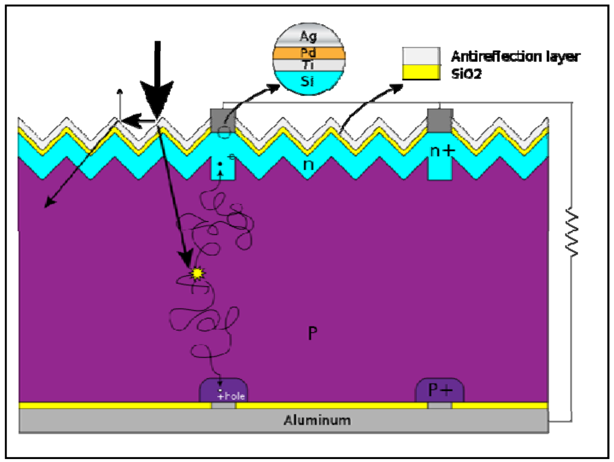
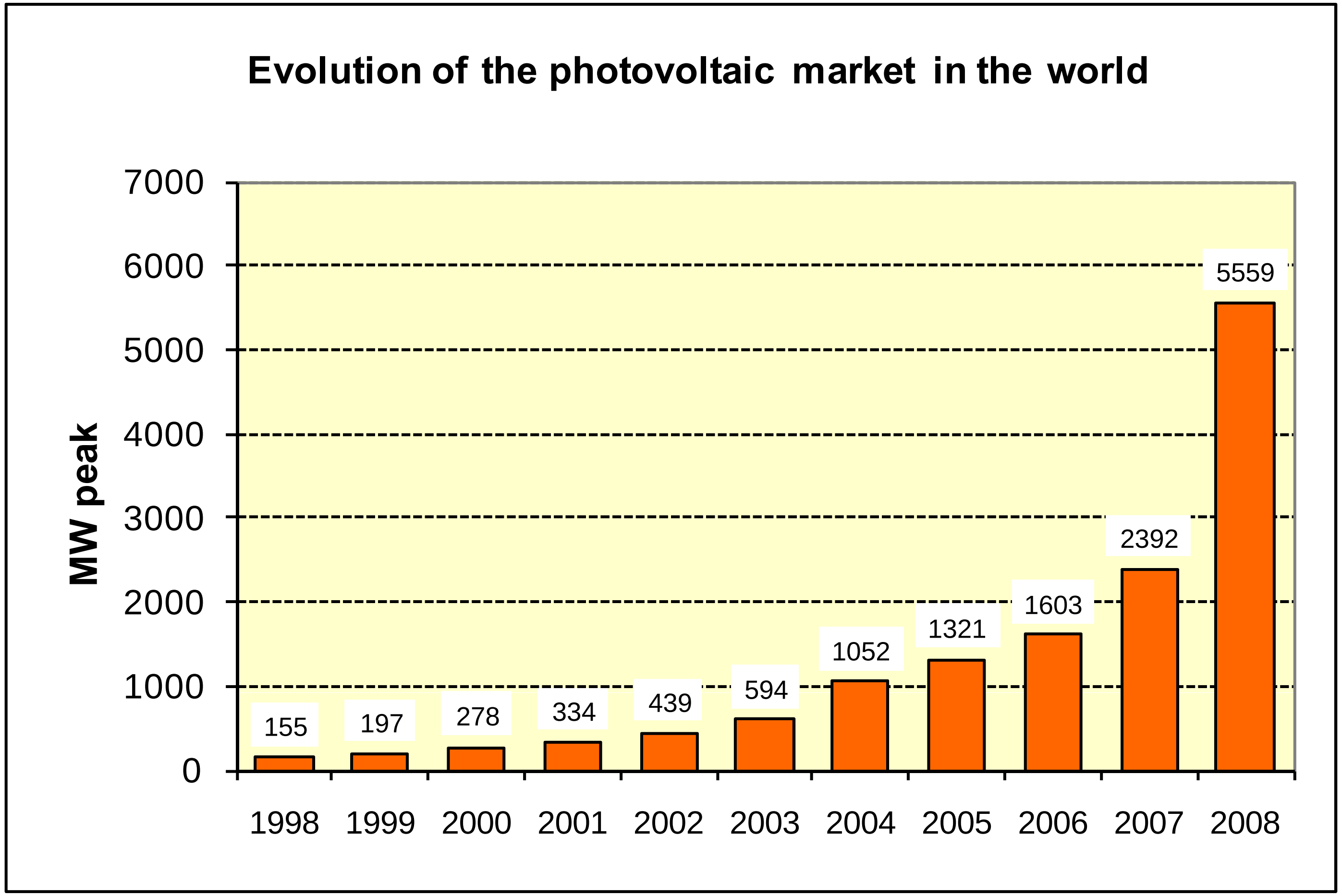


Diagram of a photovoltaic cell

Source : Wikipédia

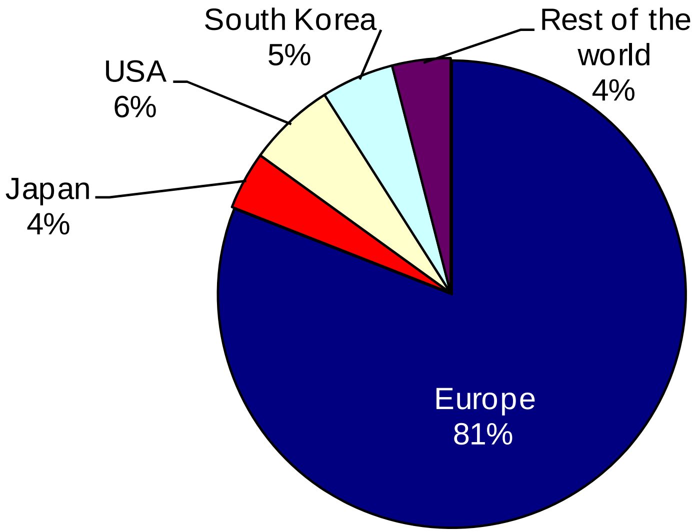
A booming form of energy…

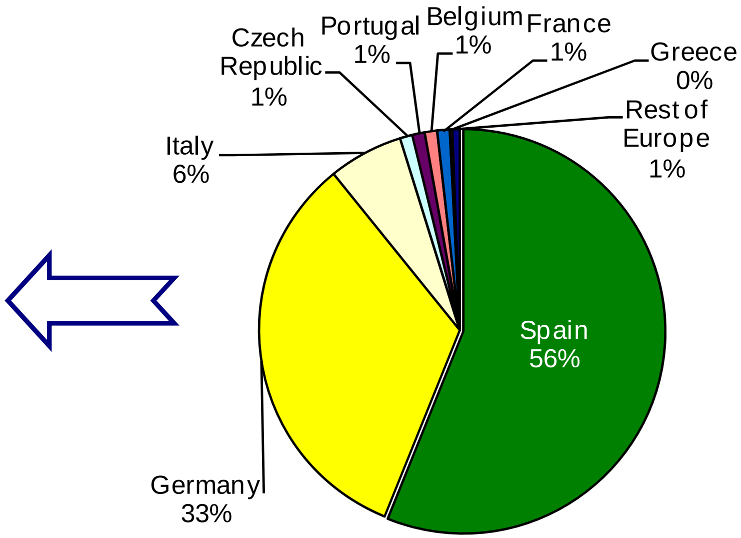


Source : EPIA

…in unexpected markets

- **Mainly in Europe**

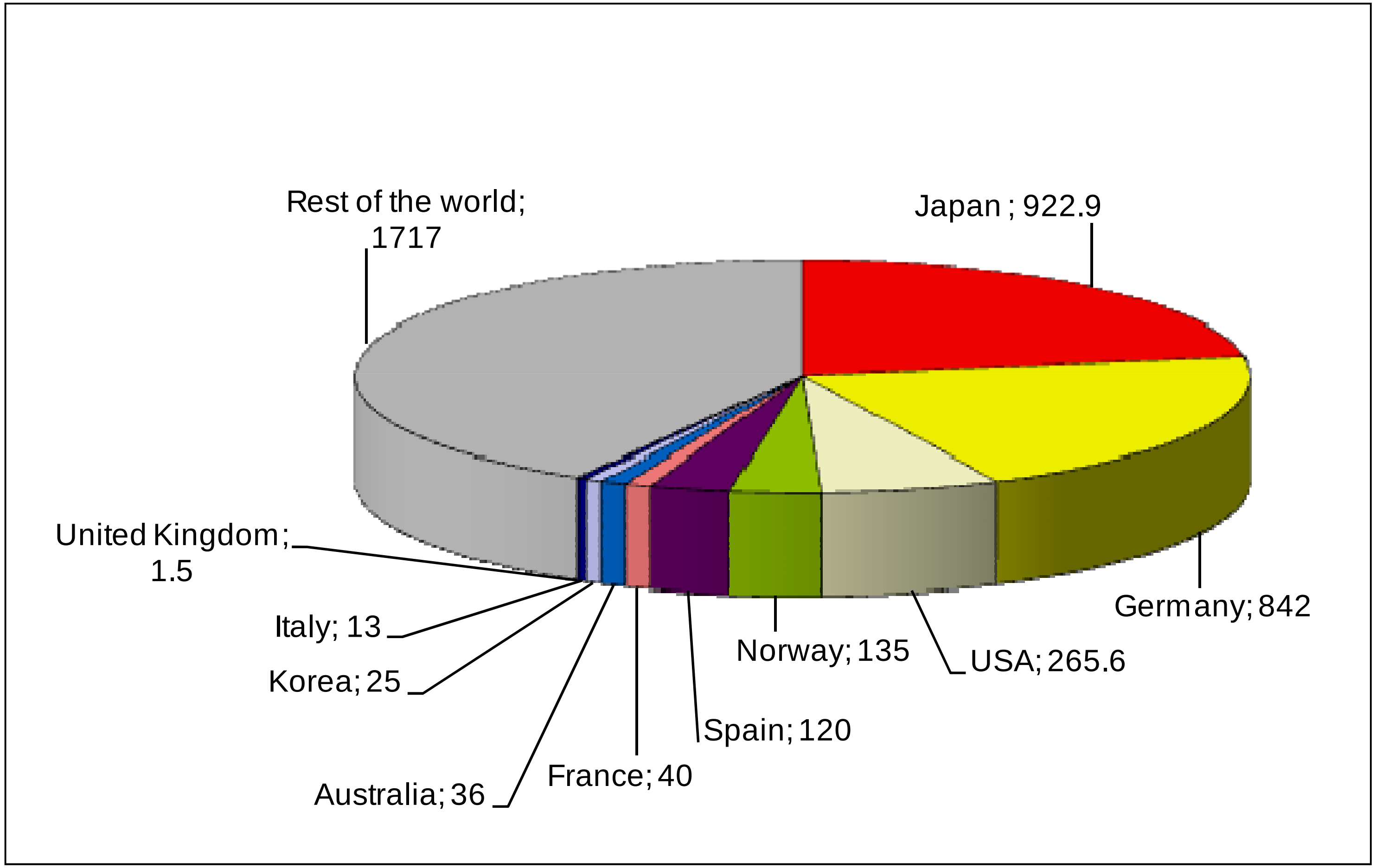




Photovoltaic market in 2008

Source : EPIA

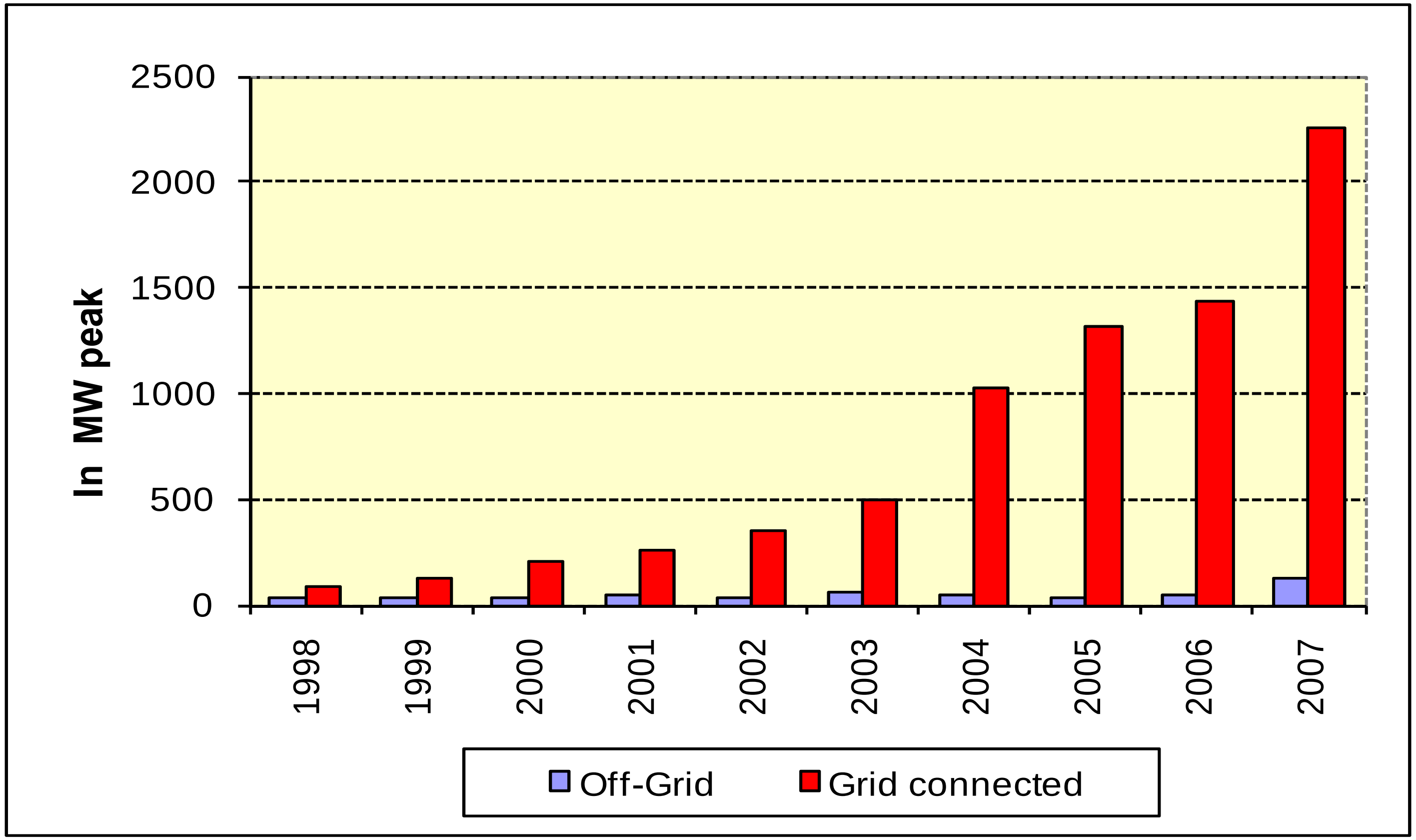
…not correlated to manufacturing countries



Distribution of production of photovoltaic cells in 2007

Source : AIE - PVPS

…in segment of markets not fitting with economic priorities



Evolution of the distribution of the photovoltaic market in the countries of the IEA – PVPS

Nota : Chinese and Indian markets both amounted circa 40 MW in 2008 according EPIA

Source : AIE - PVPS

Grid connected applications grow at 40% per year

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USA, 14 MW, 2008

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Grid connected applications grow at 40% per year

Residential area in Japan

Photovoltaics on isolated sites remain a high added value market

- **In 2011, the world market of photovoltaics for isolated sites might represent 500 MWc**
- **Main applications :**
  - Electrification programs in isolated or remote sites(60% ; CAGR > 15%)
    - Pumping, water distribution
    - Power supply in remote villages (rural electrification)
    - Street lighting, etc
  - Professional applications (40% ; CAGR > 12%)
    - Communication s& Télémétry
    - Cathodic protection

Source : Apex BP Solar

Photovoltaics and radiocommunications

- 1.6 Billion people still live without electricity
- Radio communications are of the essence for health care, education, local business etc.
- Even in developed countries, grid connectivity is unavailable in many locations
- Cellular phone base stations need to be powered 24/7
- Conventional solutions are based on diesel generators which are more and more costly, require refueling and maintenance
- PV and wind energy are currently the most attractive solution for powering base stations sites

Photo : Aomorikuma

Comparaison between various solutions for base stations power supply

Better → Worse

Criteria	Solar	Wind	Pico-hydro	Biodiesel	Fuel Cells	Fossil Diesel
Overall Ranking	●	◕	◑	◑	◔	○
CAPEX	◔	◑	●	● **	◔ ***	●
OPEX	●	●	◕	◔	○	◔
Reliability	●	◕	◕	◑	◑	◑
Supplier Availability	◕	◑	?	◔	○	●
Theft Resistance	◔	◕	●	◔	◑	○
Public Green Image	●	●	●	◑	◕	○
Operational Supply Chain Predictability	●	●	●	◔	◔	◑
Output Predictability*	◑	◔	◕	●	●	●
Resource Availability	●	◑	○	◔	○	◕

*Assuming fuel is constant **Assuming purchase of biofuel from supplier ***Fuel cell CAPEX forecast to improve rapidly

Source: GSMA Analysis

Development of green powered base stations

- GSMA anticipates 118 000 green power base stations built by 2012
- Investment cost of wind solutions is significantly lower than PV
- But wind is not so well distributed as solar
- Solar has no moving parts
- PV is a favoured choice in many regions for local sites < 2kW
- Hybrid solutions deserve consideration

Source : GSMA

Despite achieved progress, PV power remain expensive

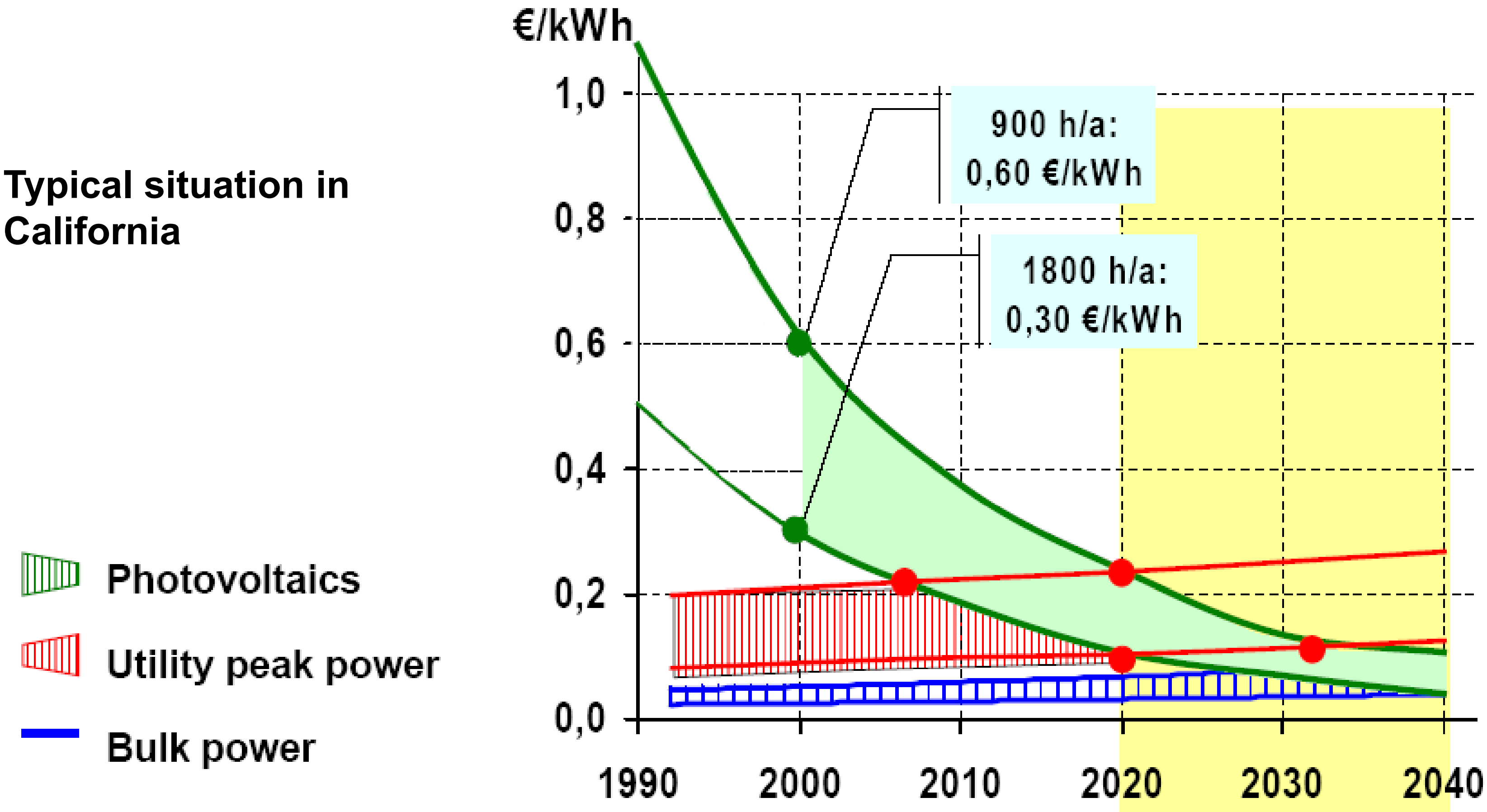
- **Modules price : circa of 1 500 to 2 000 € per kWc (1.5 to 2.0 €/Wc)**
- **Systems price : circa of 3 000 to 10 000 € per kWc**
- **MWh cost : highly dependent on irradiance ➔ location**
  - **In France, around 500 €/MWh for a 3 kW home application producing 3 000 kWh per year (initial investment : 5 000 €/W + around 20 m^2 of roof)**
  - **Around 250 €/MWh for a 5 MW power station, producing 1 225 h par an (initial investment ~ 3 000 €/kW)**

- **PV power costs are higher than those of wind energy (~ 80 €/MWh). Cost of storage, intermittency, grid connections must be added**
- **Cost of CO_2 abated is circa of 300 €/t of CO_2 in 2009 with reference to an open cycle gaz turbine and with a gas price of 10 $/MBtu**

kWc = Kilowatt crête : puissance délivrée sous conditions standard 1000 W/m2 – 25 °C

« Grid-parity » can only be reached under specific conditions

Typical situation in California



Source: RWE Energie AG and RSS GmbH

The bulk of the market remains dependent on public incentives

- Incentive policies have been put in place in many countries : Germany (« Feed-in-Tariff), USA, Italy, Japan, Spain, France
- The incidence of these policies have exceeded the forecasts: Spanish market grew 400% in 2008 (2 511 MW versus 560 MW en 2007) ➔ Spain decided a ceiling of 500 MW in 2009
- France started late but its policy is at present one of the most attractive in Europe (arrêté dated 10 July 2006)
  - Feed-in tariff of around 330 €/MWh and even 600€/MWh in case of integration of the panels into the building structure (20 years, without
  - Tax credit, 0% loans, local subsidies
  - System in place until 2012 with creation of a new tariff line for large roofs
- The French national grid is facing a huge demand of connections, from large installations (1 540 MW at 31 October 2009) as well as from small ones (< 3 6 kW)

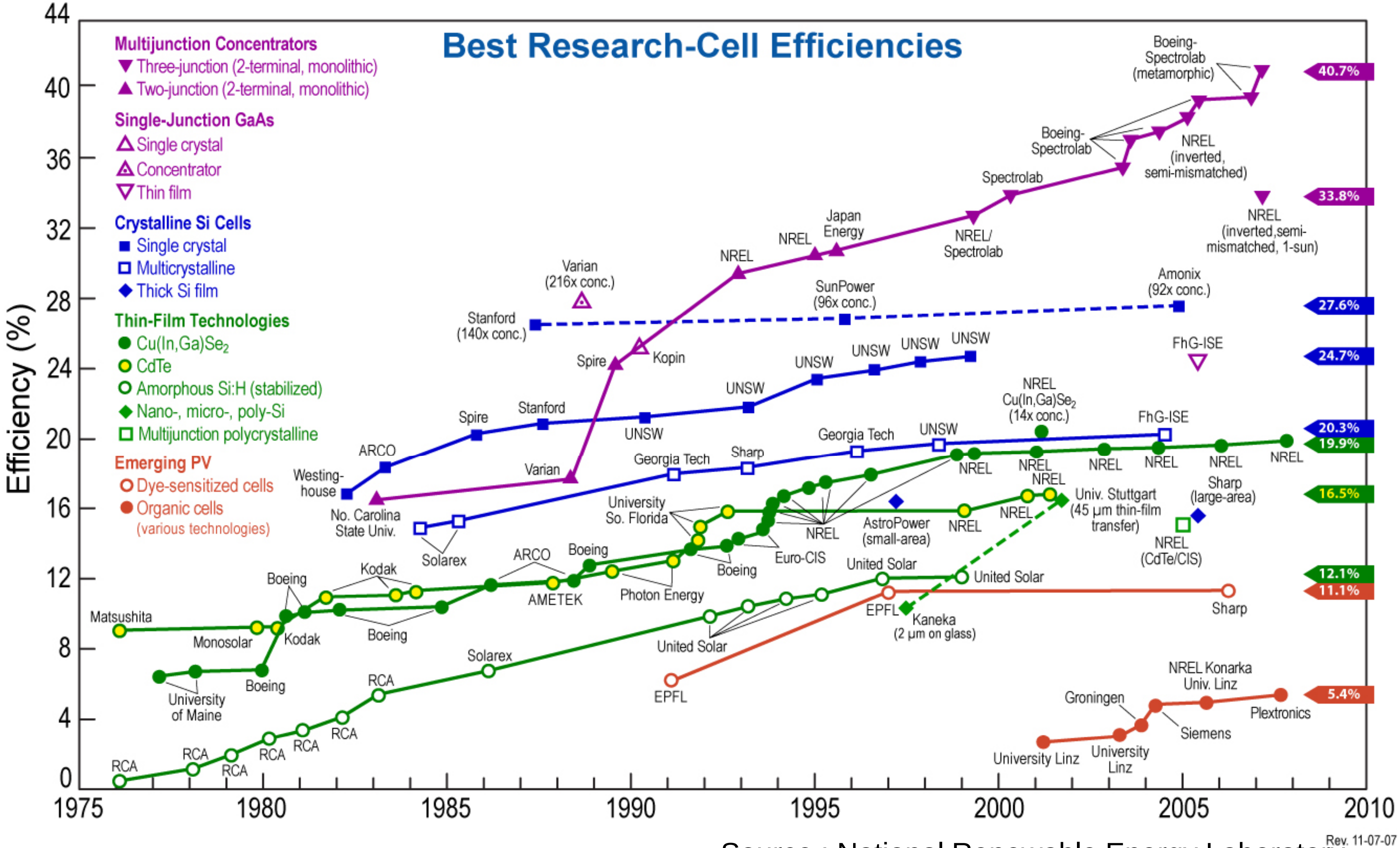
kWc = Kilowatt crête : power delivered under standard test conditions 1000 W/m2 – 25 °C

Can photovoltaics continue to grow without public support ?

- **The increase of fossil energy prices and the implementation of CO_2 taxes or of CO_2 market prices (compliance markets) will help but will not be sufficient**
- **The cost of the Watt-peak has to further decrease**
- **The objective of 1 $/Wp (modules i.e.1 400 €/kWp for systems) is, according to certain sources, already achieved (First Solar)**
- **However, the future of photovoltaics requires more!**

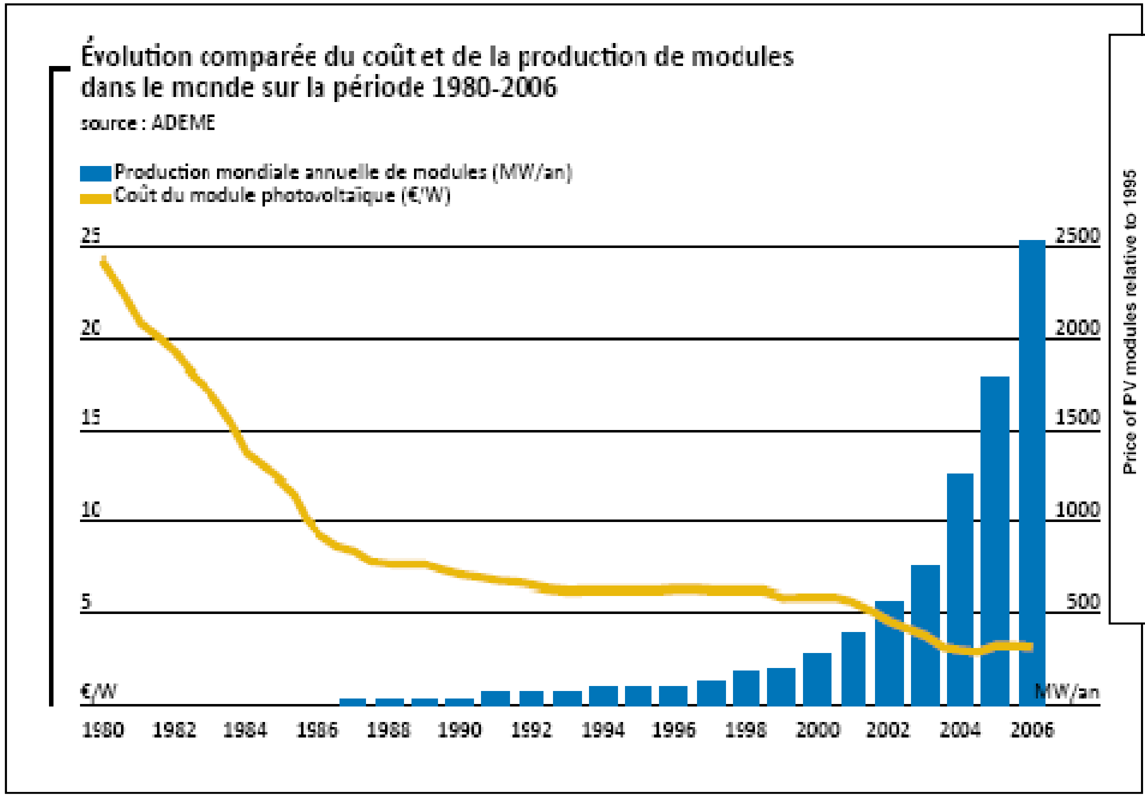
- **Is it achievable?**

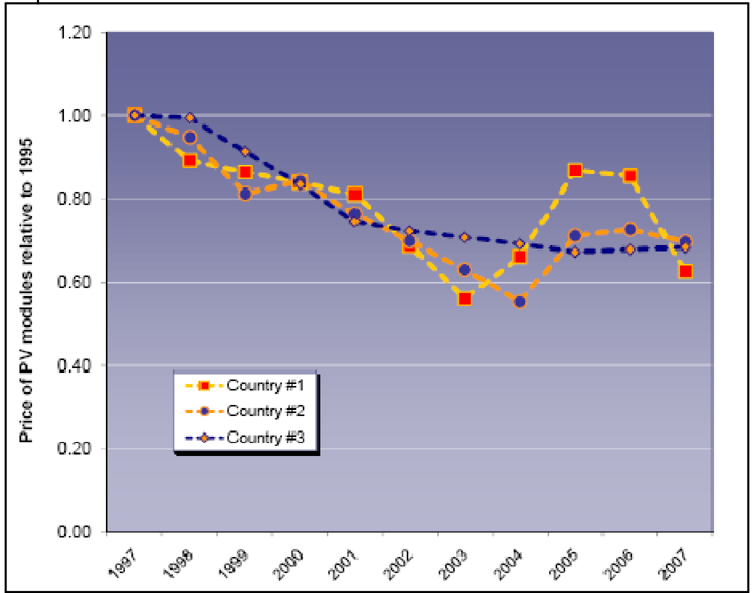
Conversion efficiencies have kept growing



Source : National Renewable Energy Laboratory

Cost reductions have been steady for 25 years





The 2004-2007 price escalation due to silicium shortage is now over

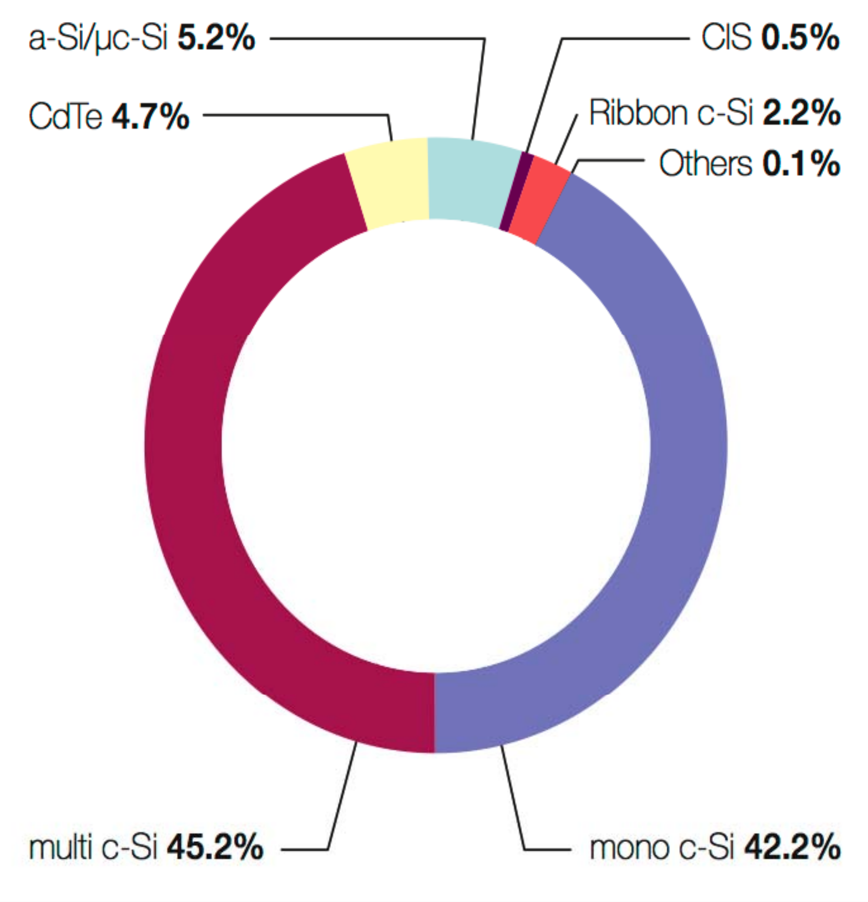
Source : AIE - PVPS

Scale effect : doubling the volume results in a cost reduction of 20%

Photovoltaics still has a very high potential for technological progress

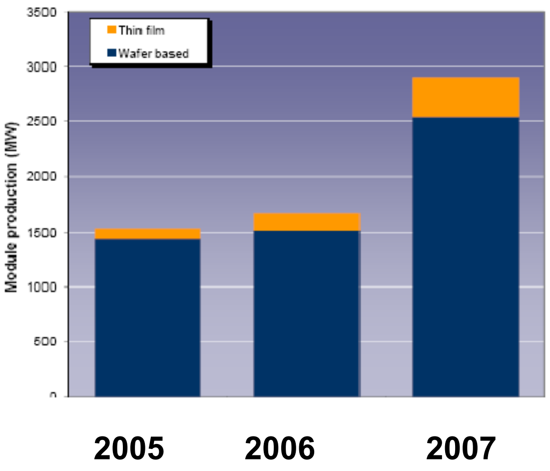
- **Reduction of manufacturing cost**
- **Increase of conversion efficiency**
- **Reduction of assembling cost for systems**
- **Increase of life time**
- **Use of solar tracking when justified**

- **Today crystalline silicon technologies are dominant**
- **But thin films are arriving on the market**
- **Third generation technologies are under development**

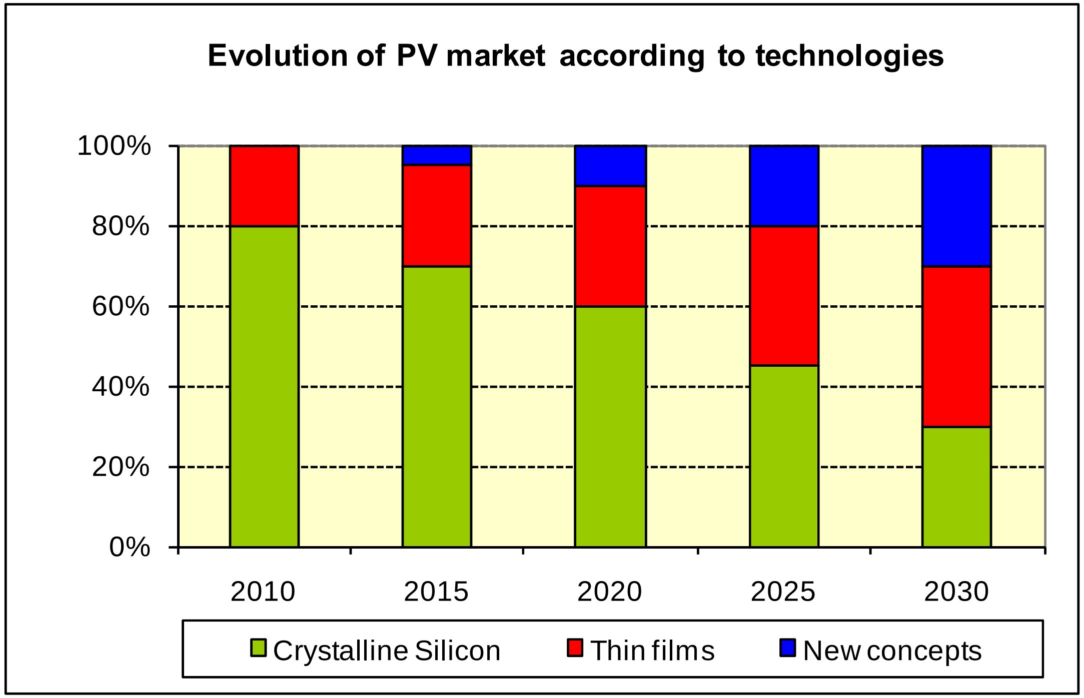


Source: Photon International, March 2008

New technologies will develop



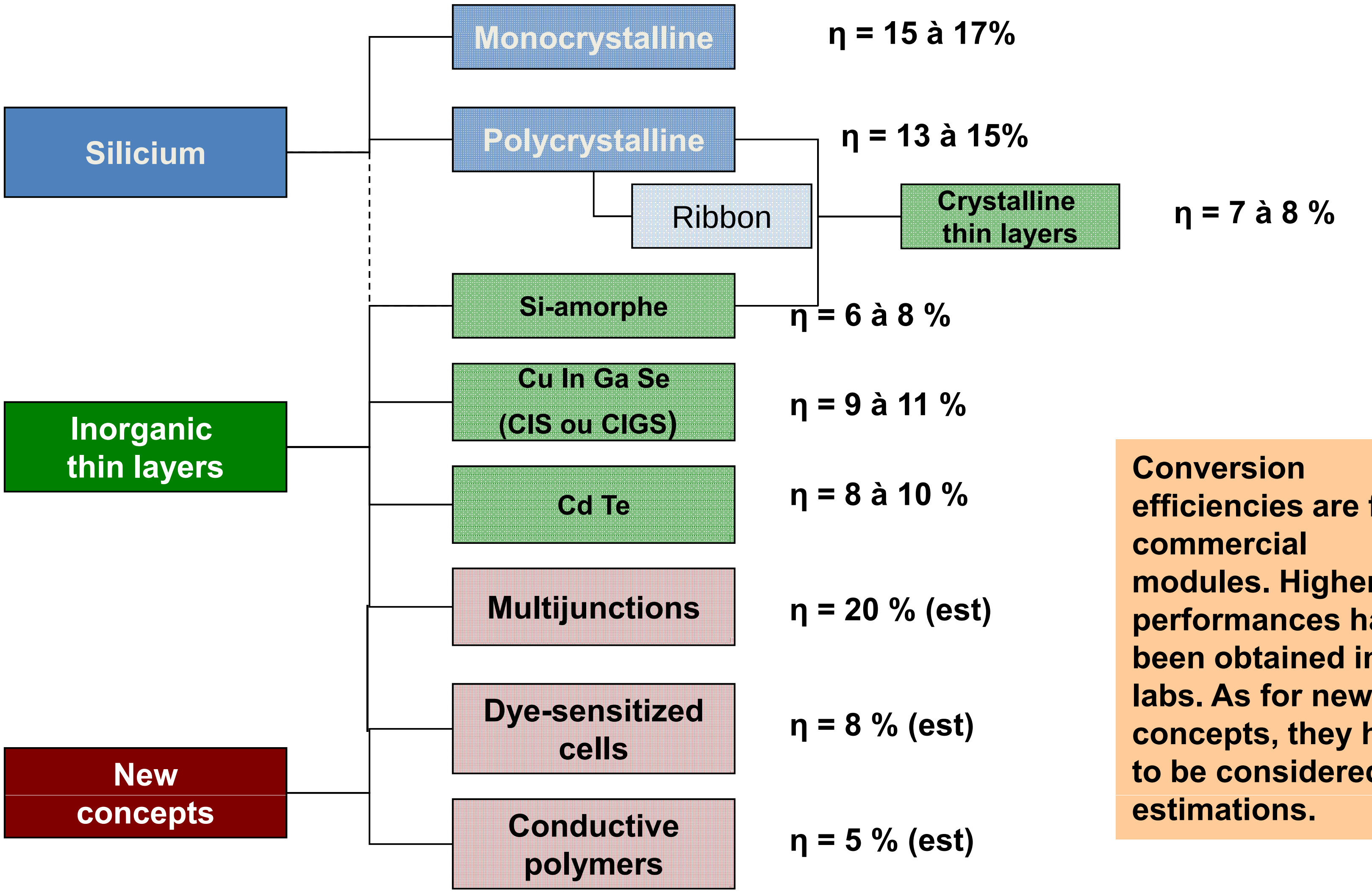
Source : AIE - PVPS



Thin films have reached the industrial stage. China is going to take the leadership.

(Source :G uy Malbranche)

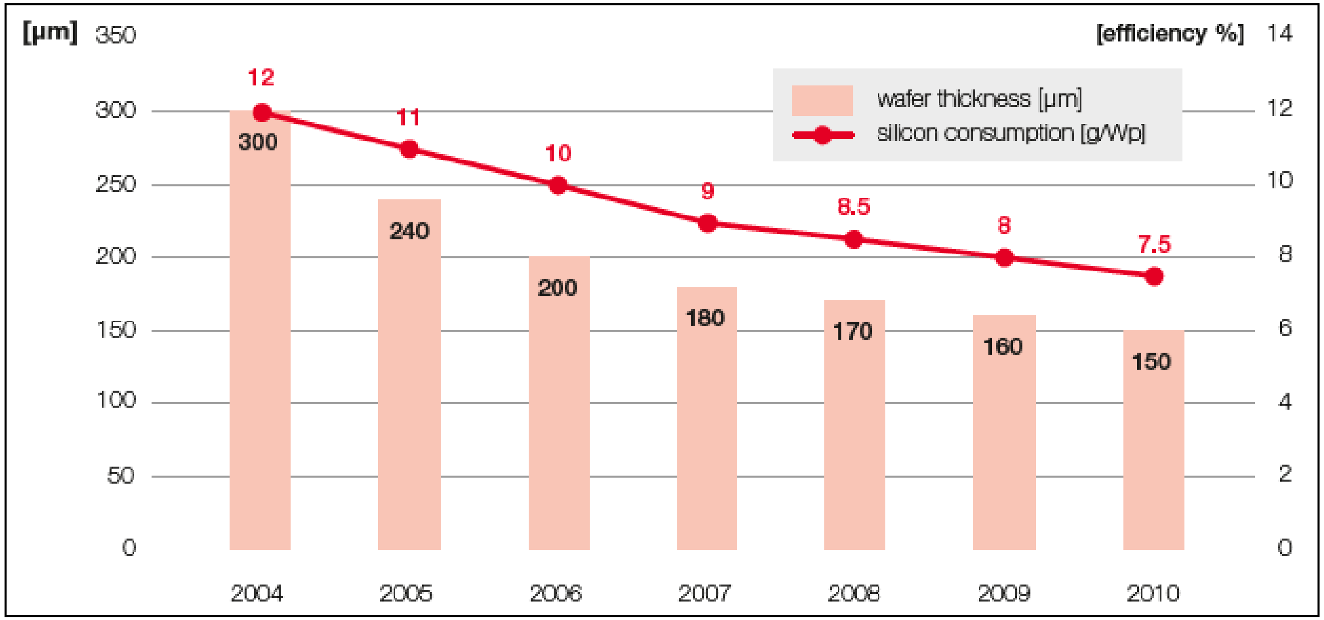
Three generation of solar cells



Conversion efficiencies are for commercial modules. Higher performances have been obtained in labs. As for new concepts, they have to be considered as estimations.

Crystalline silicon keeps progressing

- **Reduction of the cell thickness and of the Si quantity per Wp**



Source : EPIA -2008

- **Objective : 5 g/W (20 g en 1990)**
- **Improvement of the whole process**

Thin layers may constitue a major technological breakthrough

- Strong reduction in material mass (active layer of 2 µ) – No sawing
- ➔ Cost reductions
- Diversity of supporting materials, including flexible ones
- Possibilities of developing transparent or colorized thin films

However :

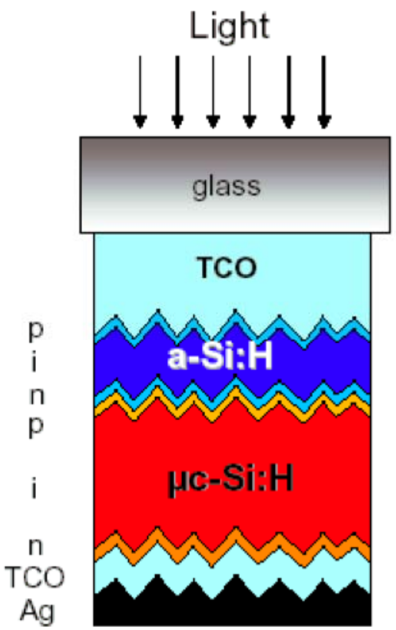
- Materials must be abundant and cheap (problem with Indium)
- Non polluting (problem with Cadmium)
- Stable (for decades)

Silicium amorphe sur inox (Unisolar)

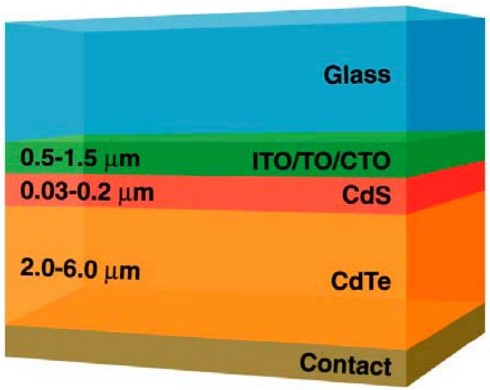
Silicium amorphe sur plastique (Flexcell)

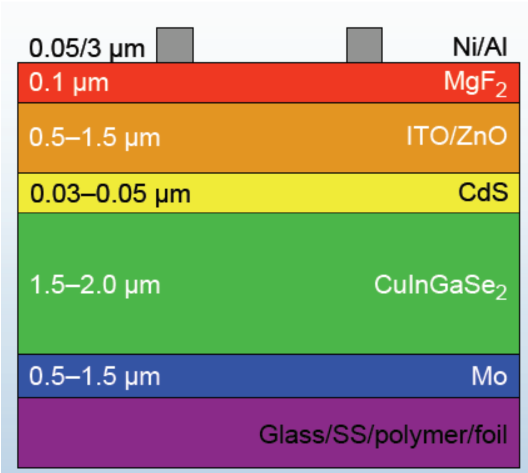
More than 150 materials have been tested up to now.

The three major thin-film technologies



(d'après J-F Guillemoles)





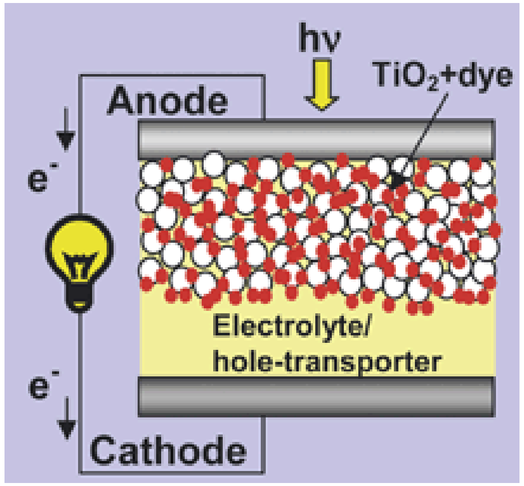
Amorphous Silicon: **Discovered by fluke in 1960 – Efficiency relativey low but well adapted to diffuse radiation – Leader : Sharp**

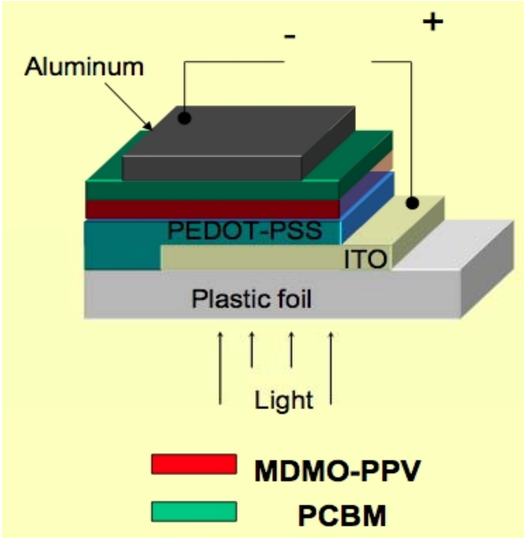
Cadmium telluride: **God performances but handicaped by the Cd issue – Leader: First Solar**

Chalcopyrite films ($CuIn_xGa_{1-x}Se$) : **Good performances but handicaped by the Indium issue -Leader: Nano Solar**

(Bernard Equer)

The third generation





Multijunctions:

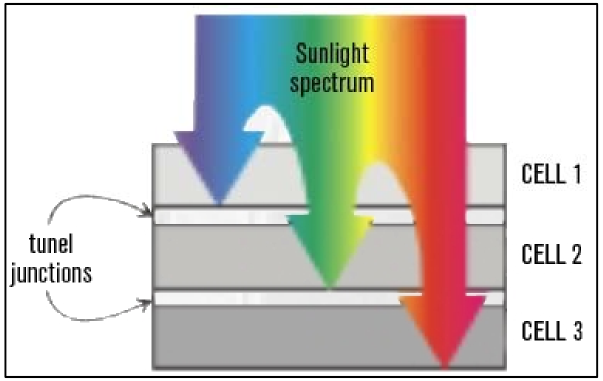
Towards high conversion factors

Dye-sensitized cells:
Discovered in1991 (Grâtzel cells) – Not yet industrialized.

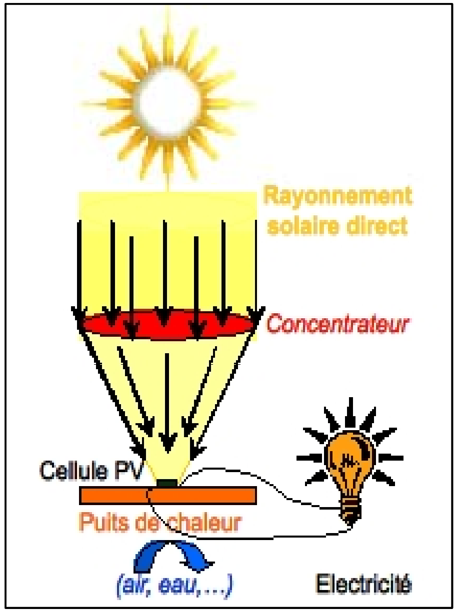
Organic semi-conductors:
Disocovered in 1970 – Low efficiency – Stability not yet proven

Conversion efficiency can also be improved

- Thermodynamic limit : around 87%
- Conversion factors of 42% have been reached in several labs
- 20% are commercially targeted for 2010/2012
- Two main approaches: multijunctions and concentration



Multijunctions:
Multiple thin films
Each with a characteristic band gap
Better absorption of the whole spectrum



Concentration:
Possibility of attaining > 40% in efficiency
But cooling and tracking are necessary

(selon Bernard Equer)

Conclusions

- No doubt that the objectives of 20% conversion efficiency and 1 $/Wp will be reached
- Beyond these milestones, new technological breakthroughs are possible
- Grid-parity may be achieved but remains questionable, especially under our latitudes
- Public incentives are today supporting an important “grid connected” market
- But likely public incentives will decline and, like in Spain, artifical markets may collapse
- Off grid markets, which are today the minority, will benefit from technological progress, increase of oil price and, possibly, from support resulting from local or international CO_2 emissions reduction programs
- Radiocommunications is one of the key markets among off-grid applications, benefitting from progress in PV as wall as in batteries.

KB Intelligence

Thank you for your attention

Presentation available

on www.kbintelligence.com and on www.hauet.com