

*ESPCI-ParisTech & « Sauvons le Climat »
29 Octobre 2009*

L'énergie Solaire : Un rendez vous à ne pas manquer

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Photovoltaïque

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L'IRDEP est localisée à Chatou sur l'un des trois sites d'EDF R&D

Equivalences énergétiques

1 Joule = 1 W.s

1 kWh = $3,6 \cdot 10^6$ J = 3,6 MJ

1 Tonne de pétrole = 11.6 MWh

1 baril = 159 litres

Une personne: environ 200 W

Un cheval: environ 1kW

La ressource

Dans l'antiquité : les miroirs d'Archimède



Le solaire thermique arabe au moyen âge

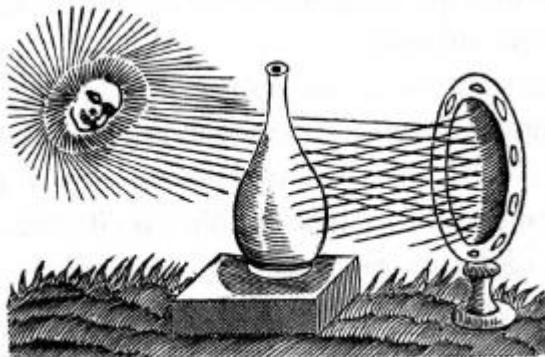


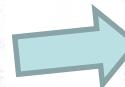
Fig. 12.

1551 Adam Lonicer, Histoire Naturelle



1726 Le rôle des dogmes

Cependant l'opinion de Descartes avait fini par prévaloir en France au point d'y faire regarder comme une fable l'histoire des miroirs ardents d'Archimède. Aussi, n'est-ce guère que soixante-quinze ans après la mort de l'illustre philosophe qu'un physicien français, Dufay, ose en appeler de ce jugement.



1869 A. Mouchot, La chaleur solaire et ses applications industrielles, 1869

« Ainsi, le soleil par un beau jour lance pendant 8 à 9 h à Paris un travail de près d'un cheval vapeur par mètre carré »

— 92 —

« Une pierre aurifère se brisa et commença à fondre au bout de 7 secondes et demie.

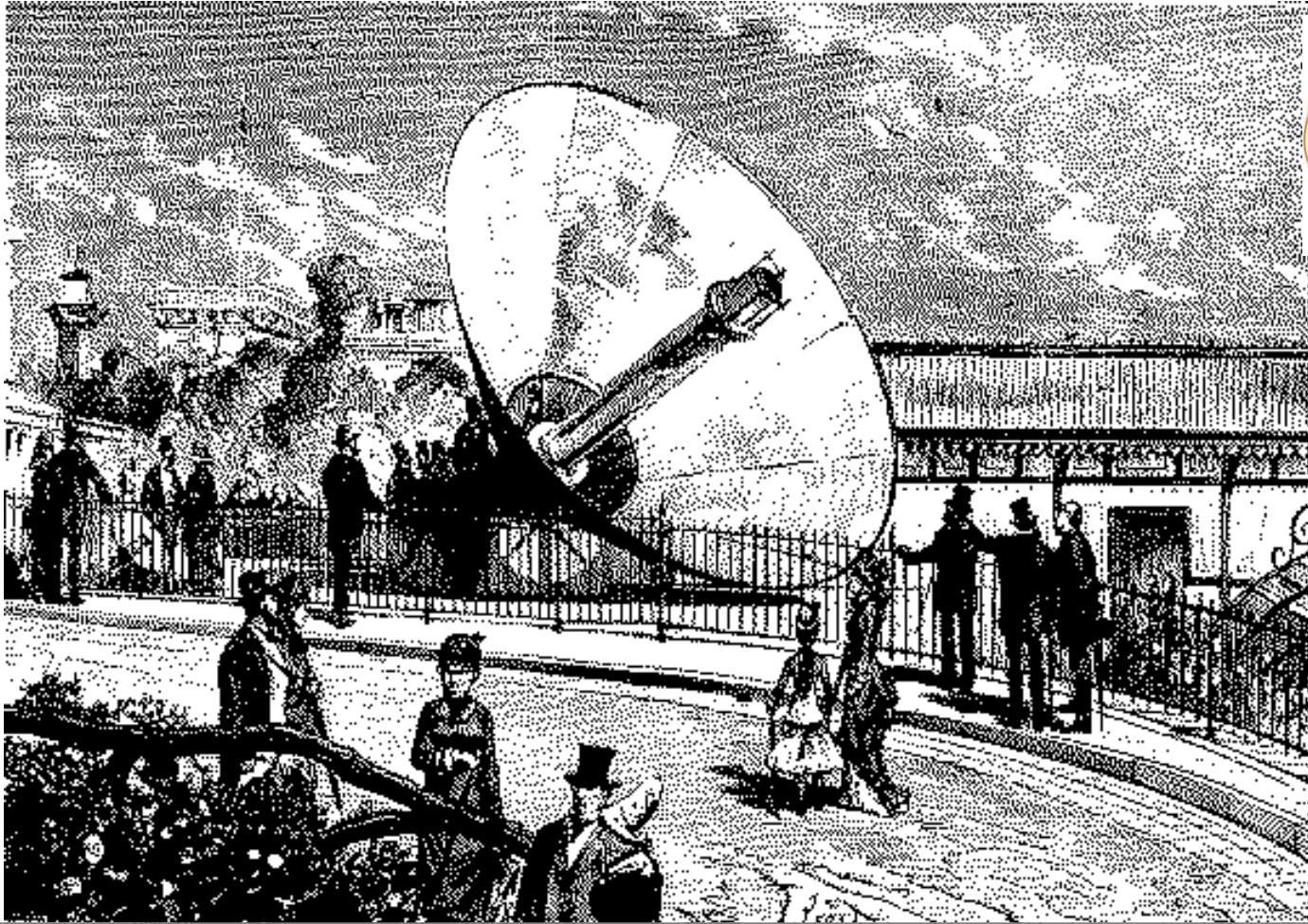
« Un demi-sou du roi Georges se fondit en 16 secondes ; de l'étain, en 3 secondes ; de la fonte de fer, en 16 secondes ; de l'ardoise, en 3 secondes.

« Une tuile mince se fondit au bout de 4 secondes et fut vitrifiée au bout de 80.

« Un os se calcina en 4 secondes, et fut vitrifié au bout de 33.

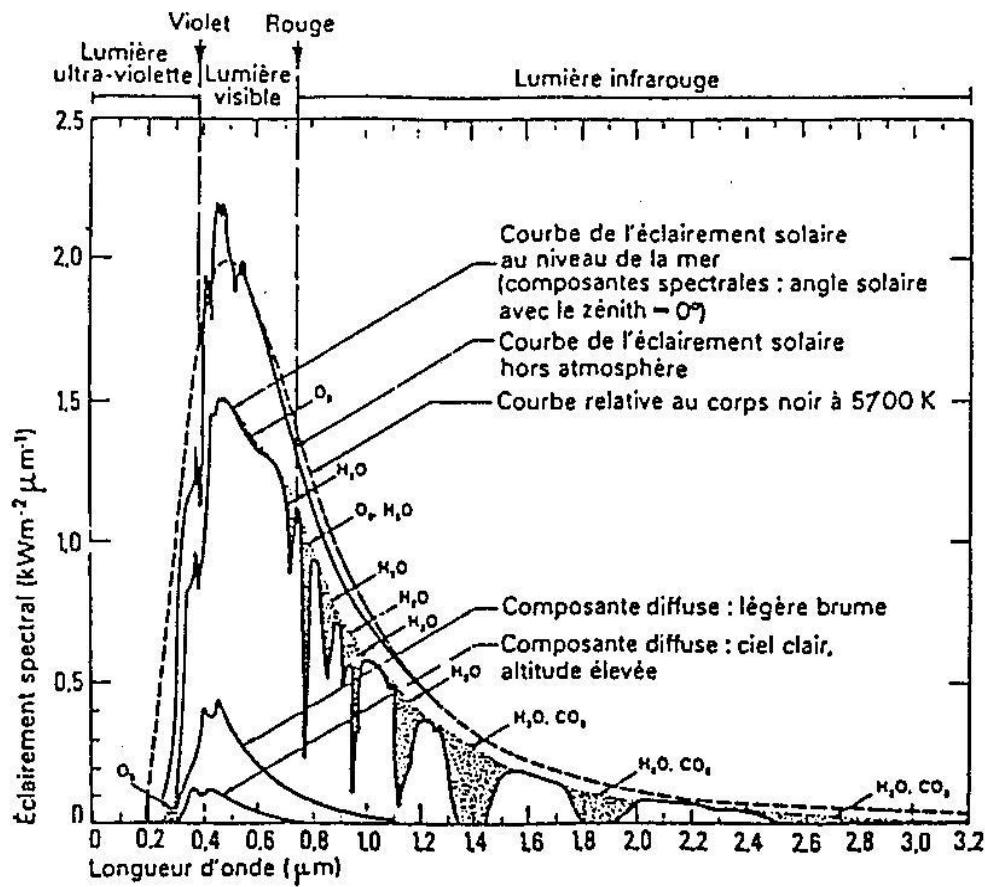
« Une émeraude se fondit en une substance semblable à une turquoise. Un diamant perdit les 7/8 de son poids.





Machine solaire à l'Exposition Universelle de Paris, 1878

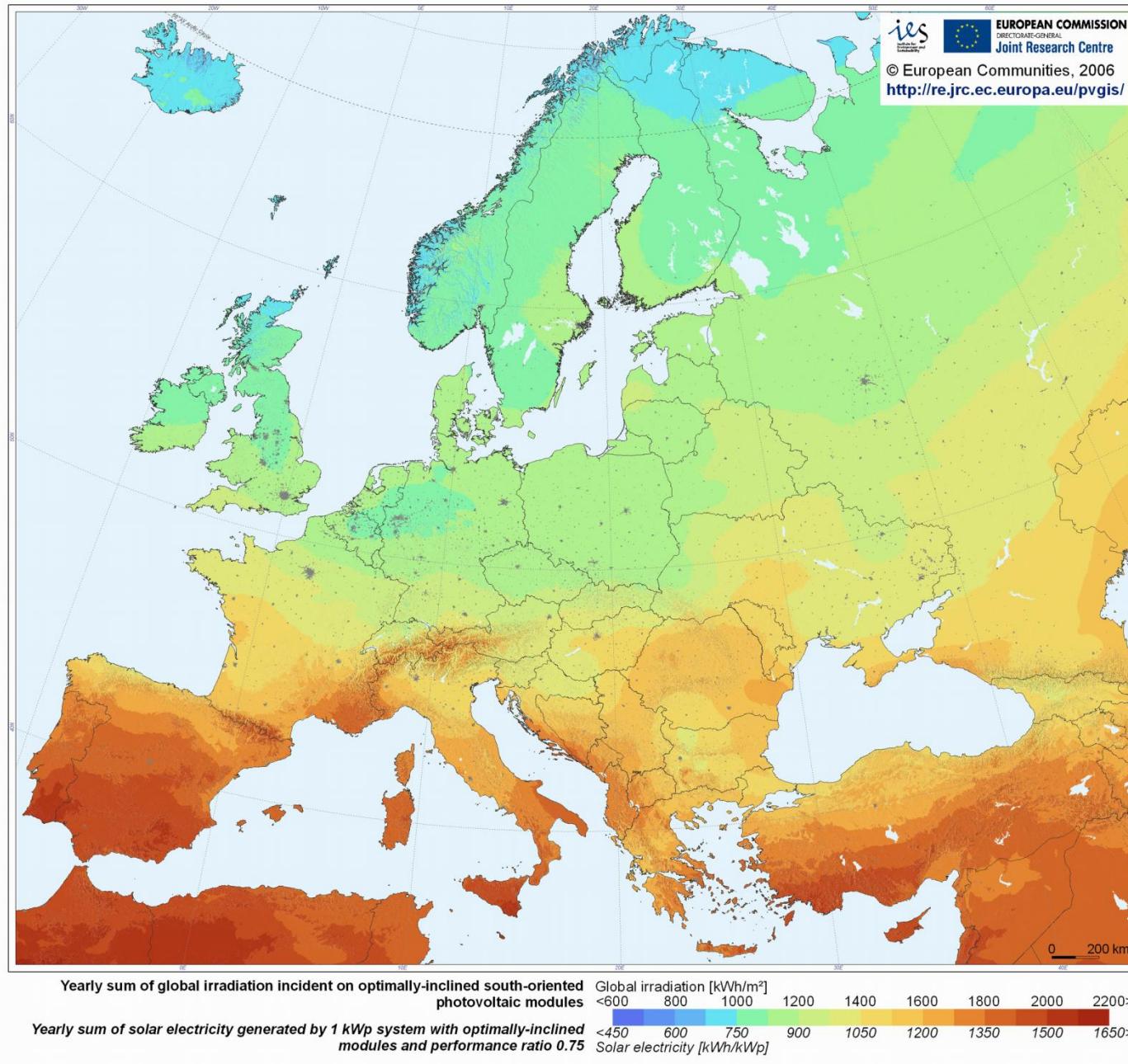
En 1860, le professeur de mathématiques du Lycée de Tours, Augustin Mouchot a écrit "Eventuellement on ne trouvera plus de charbon en Europe...que fera l'industrie ?" Sa réponse était la maîtrise de l'énergie solaire. Après 20 ans de recherche, il a inventé la principe de la poursuit du soleil avec un capteur à concentration. La machine exposée à Paris avait un réflecteur en cuivre argenté et un circuit hydraulique dans un cylindre peint en noir, elle produisait assez de vapeur pour faire marcher un moteur avec la puissance d'un demi cheval.



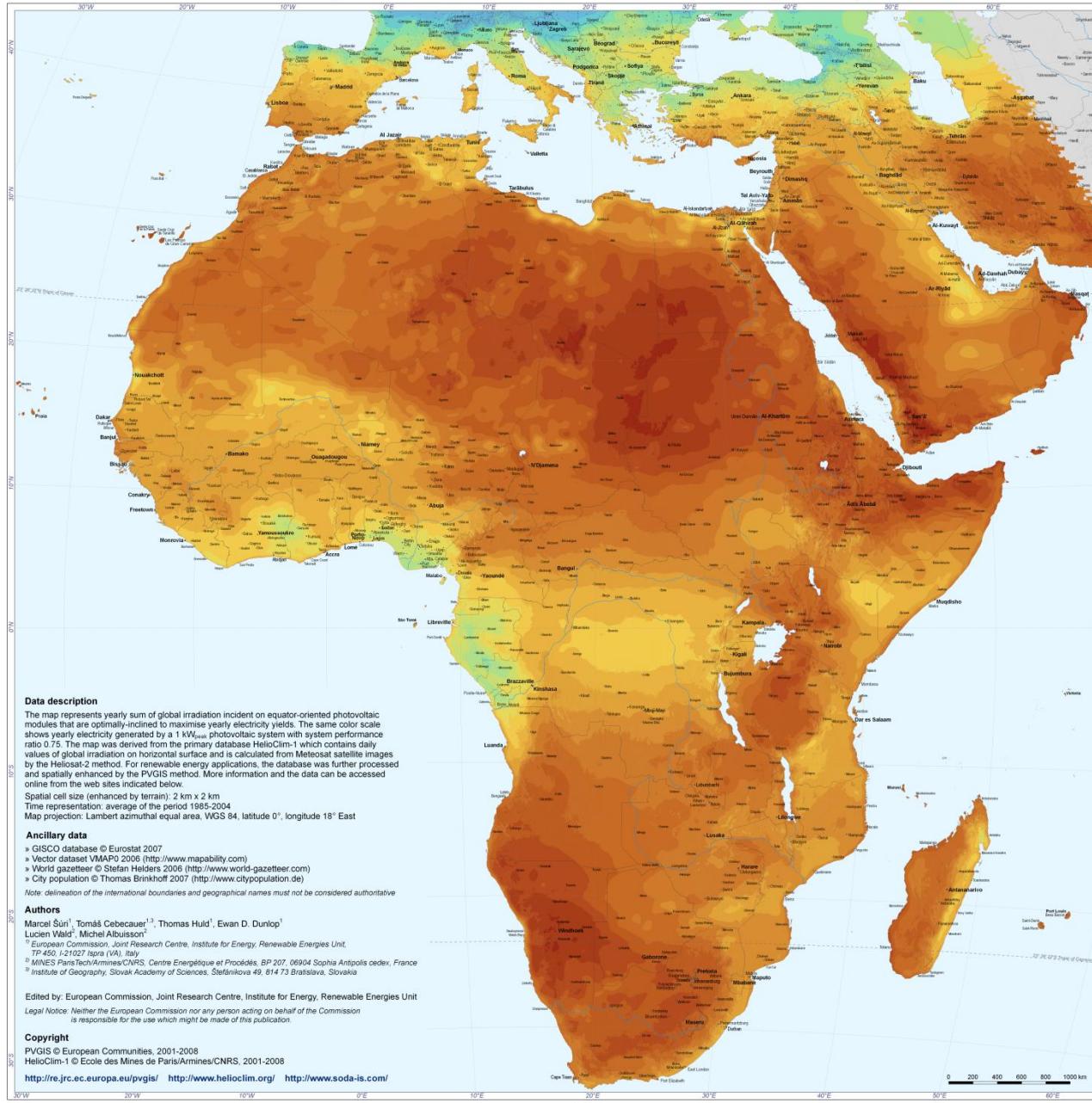
Dans l'espace: 1350 W/m^2
En un an: $10,6\text{ MWh/m}^2$



Photovoltaic Solar Electricity Potential in European Countries



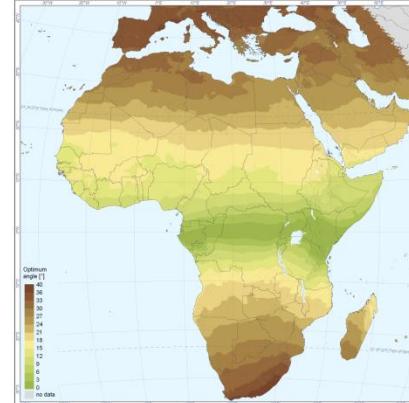
Photovoltaic Solar Electricity Potential in the Mediterranean Basin, Africa, and Southwest Asia



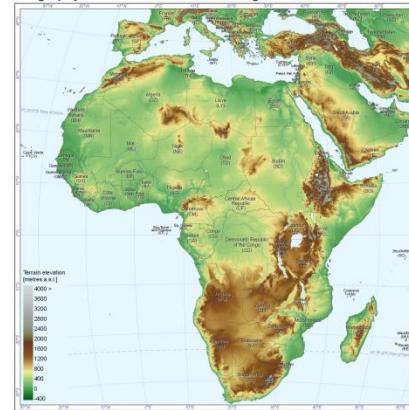
Yearly sum of global irradiation incident on optimally-inclined equator-oriented photovoltaic modules

Yearly sum of solar electricity generated by 1 kW_{peak} system with optimally-inclined equator-oriented photovoltaic modules and system performance ratio 0.75

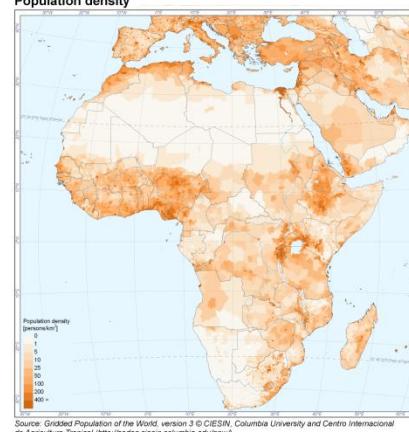
Optimum inclination of equator-oriented photovoltaic modules to maximize yearly energy yield

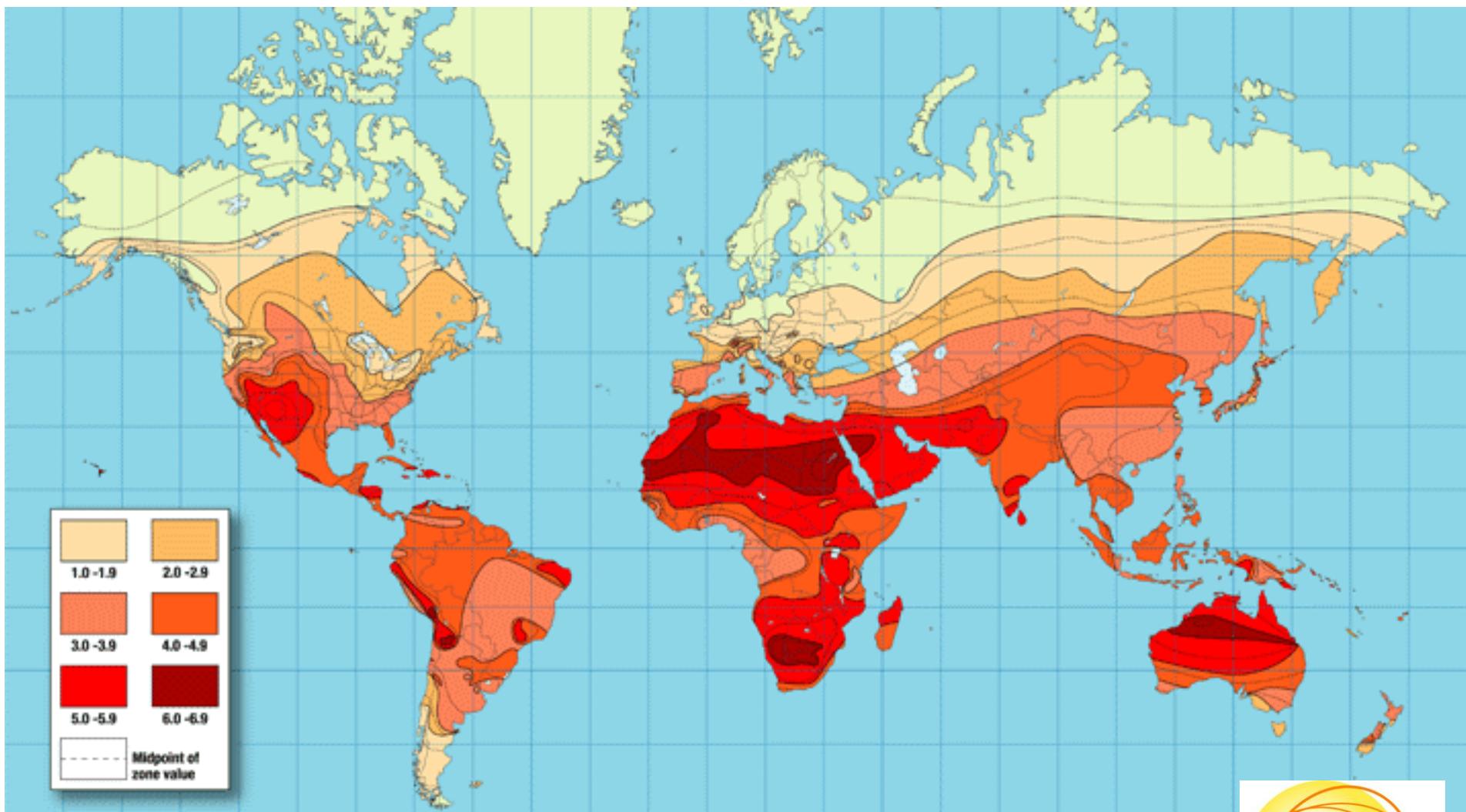


Orography and names of states and regions with ISO codes



Population density

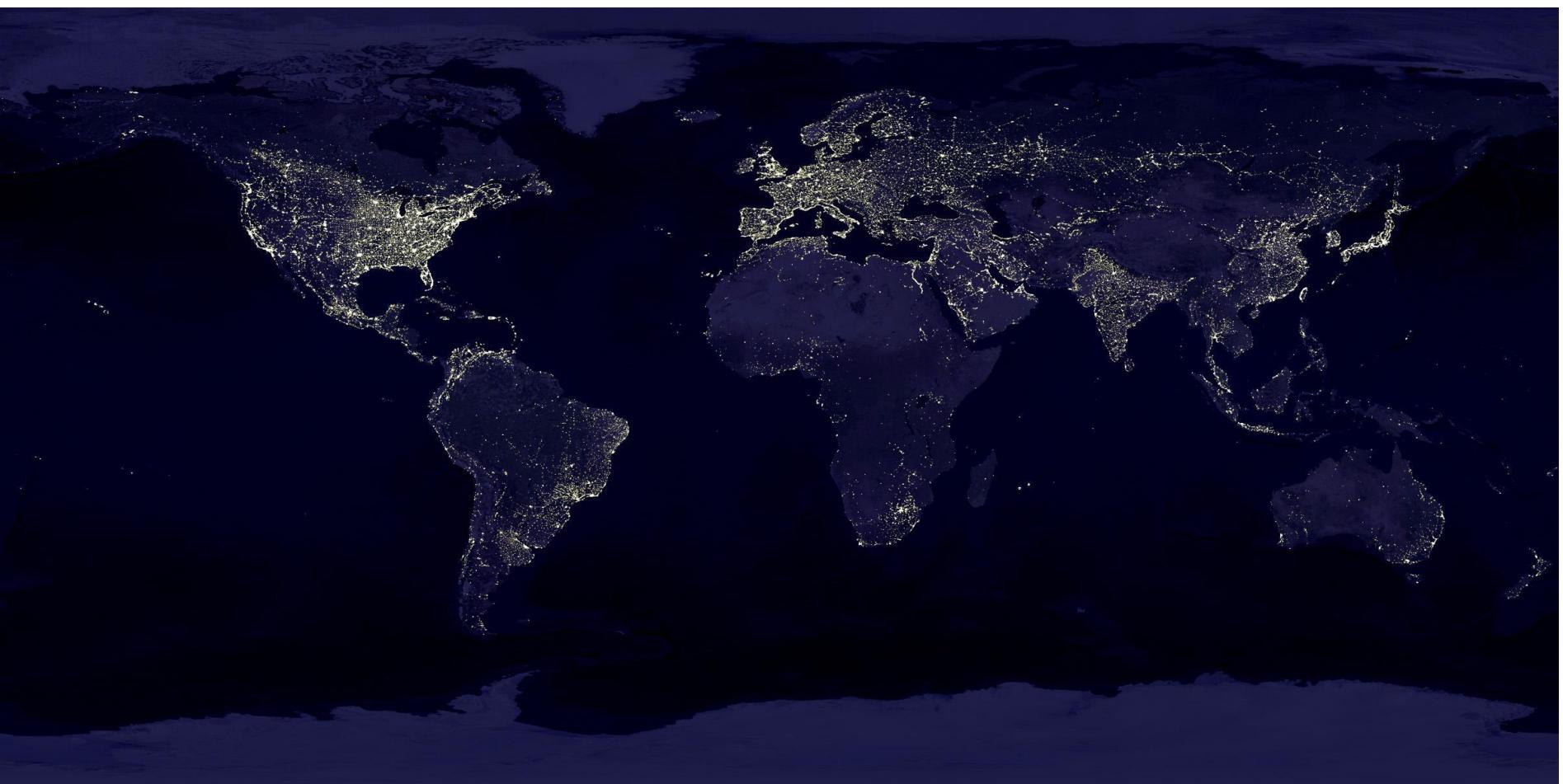




http://www.oksolar.com/abctech/images/world_solar_radiation_large.gif



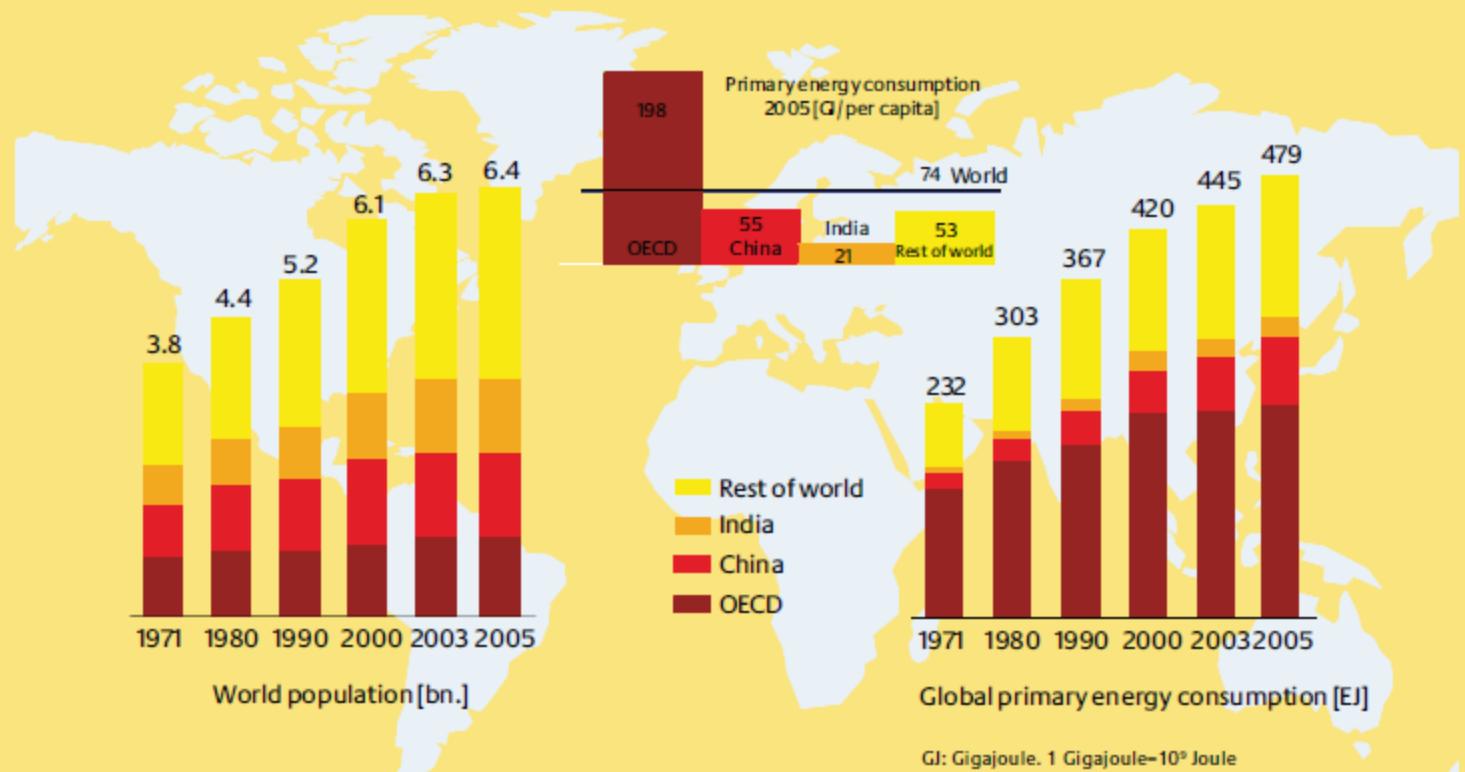
La demande en énergie



<http://www.ocean.udel.edu/windpower/ResourceMap/index-world.html>



Development of world population and global primary energy consumption

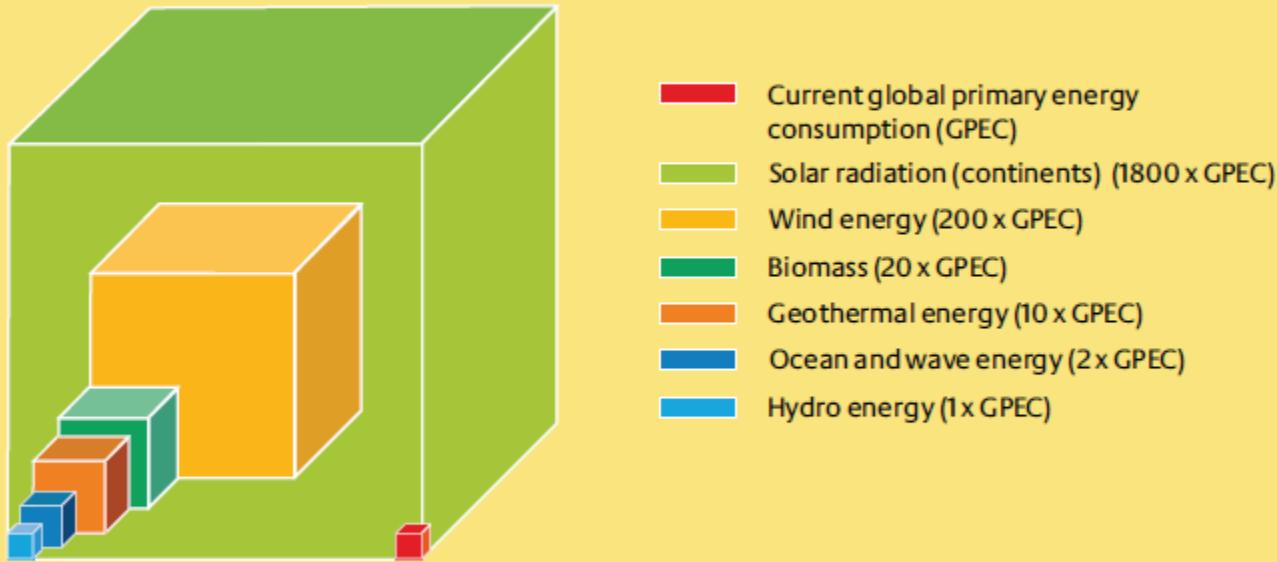


Source: Staiß, F (2007): Jahrbuch Erneuerbare Energien 2007.

http://www.irena.org/downloads/IRENA_brochure_EN.pdf



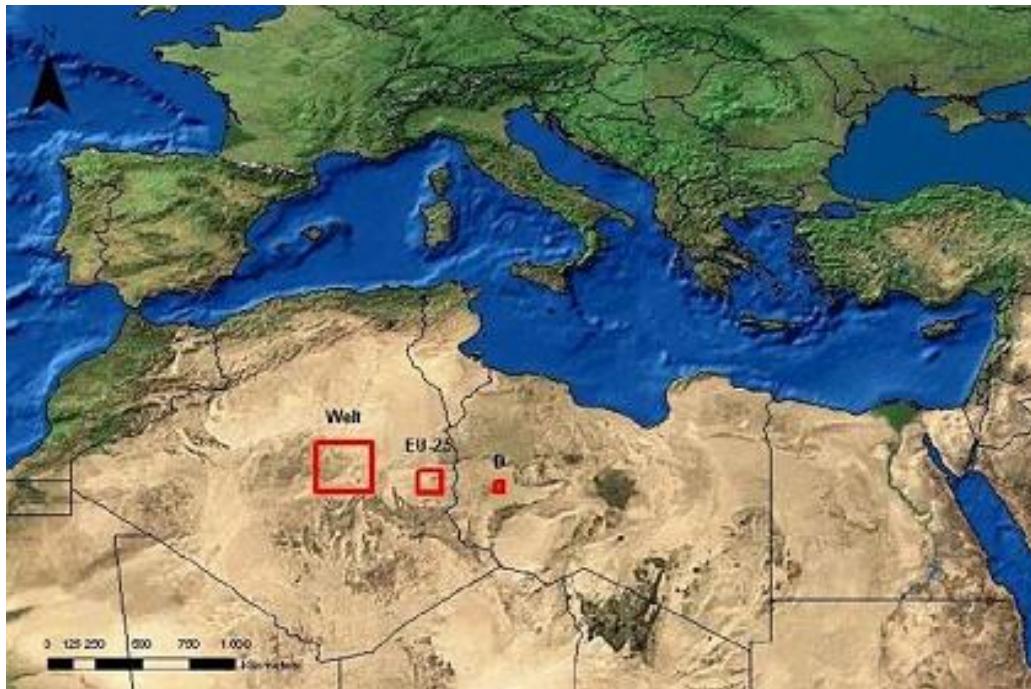
The physical potential of renewable energies



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

Données de base

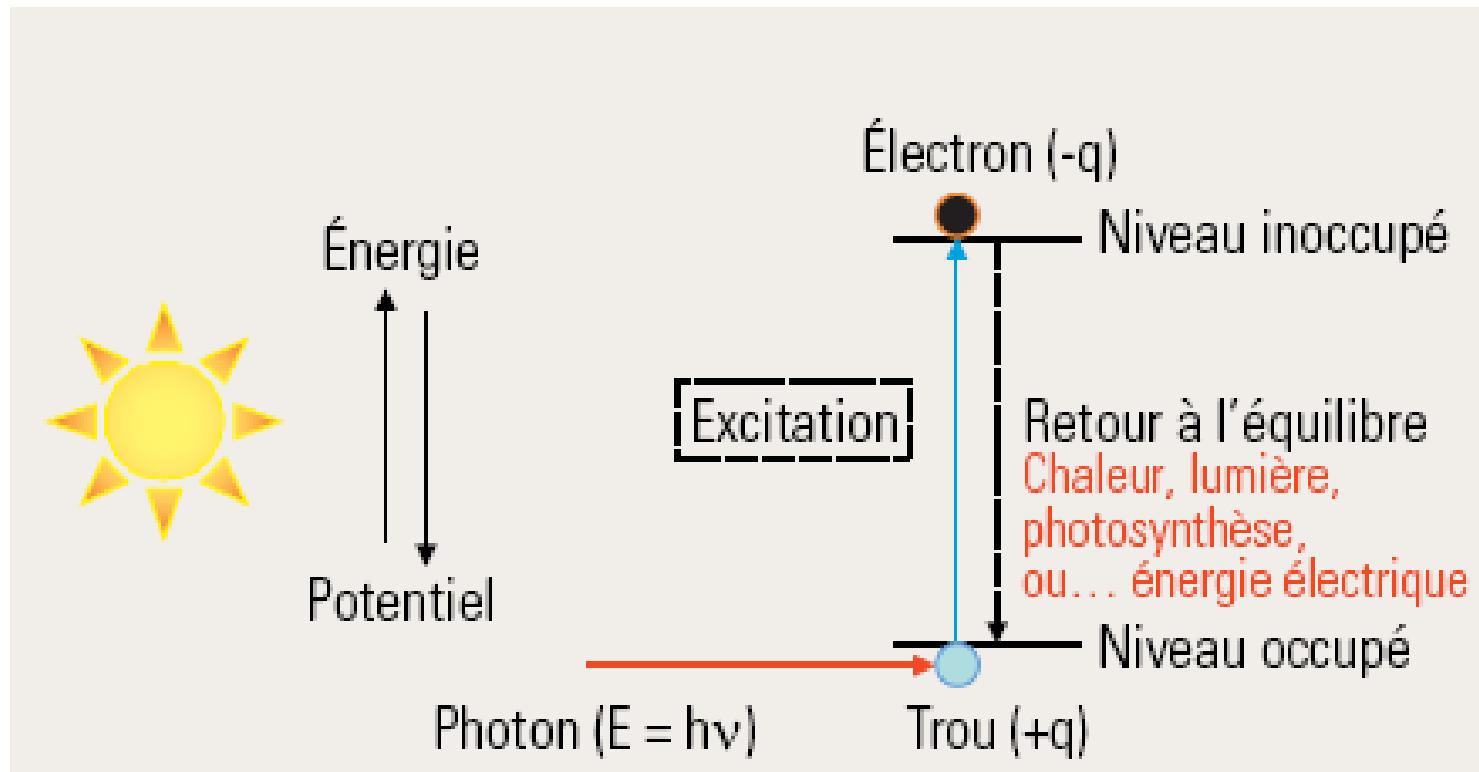
- Puissance incidente standard (AM1.5) : 1000 W/m^2
- Energie incidente par an: 0.8 MWh/m^2 to 3 MWh/m^2
- Equivalent 550 TWh/an en France : $23 \times 23 \text{ km}^2$
- Infrastructures France (toits, routes...) : 30000 km^2
- Energie mondiale : 500 ExaJoule/an (10^{18}) : $170 \times 170 \text{ km}^2$ au sahara



Spiegel on Line Photo Gallery

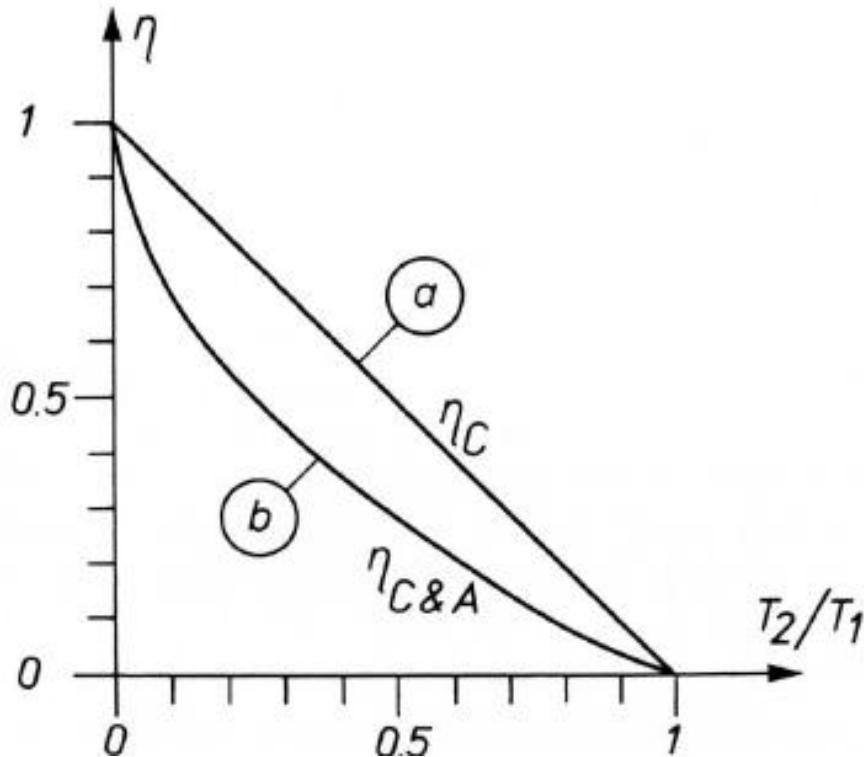
The left square, labelled "world," is around the size of Austria. If that area were covered in solar thermal power plants, it could produce enough electricity to meet world demand. The area in the center would be required to meet European demand. The one on the right corresponds to Germany's energy demand.

Comment faire ?



La conversion thermique

Systèmes solaires concentré(CSP)
Les systèmes sans concentration



Carnot

$$\eta = 1 - \frac{T_2}{T_1}$$

Curzon et Ahlbom

$$\eta = 1 - \sqrt{\frac{T_2}{T_1}}$$

T2 = 20°C

T1= 250°C

T1= 350°C

T1=700°C

T1=1000°C

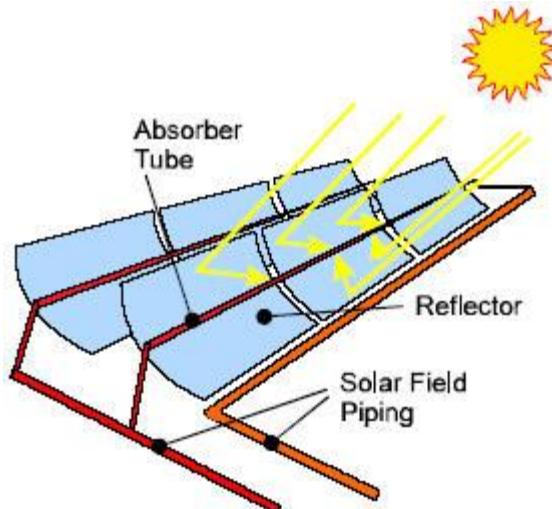
a:44% -b:25%

a:53%-b:28%

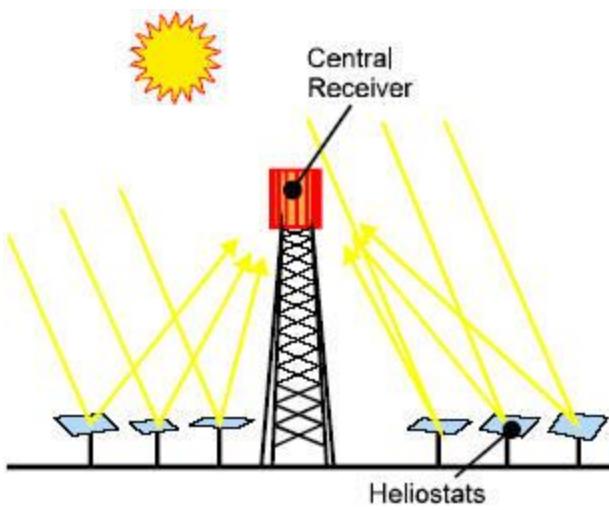
a : 70%-b: 40%

a: 77 %-b: 50%

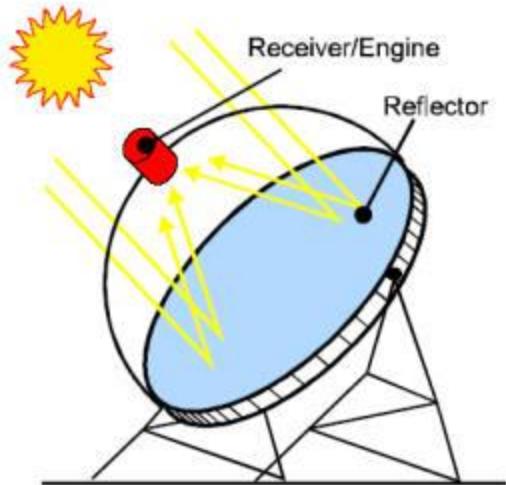
Centrales à capteurs cylindro-paraboliques



Centrales à Tour



Centrales à disques paraboliques



Centrales à tour

Température de 600°C

Début de l'expérimentation en 1976 à Albuquerque au USA (Laboratoire Sandia)
63 m, 222 héliostats puissance thermique de 5 MW

France : Themis projet EDF-CNRS démarré en 1976 exploitation 1983-1986



Redémarrage en 2006
201 héliostats – moitié pour PV-
moitié pour chaleur 1000°C au lieu de 500°C

Projet Pegase (PROMES-CNRS, Perpignan)

Targassone , Pyrénées Orientales

[http://www.outilssolaires.com/pv/prin-
centraleB.htm](http://www.outilssolaires.com/pv/prin-centraleB.htm)



Centrale Solar 2 (Edison Californie, 1996)

1926 Hélisostats

Technologie sel fondu caloporteur

Sel fondu (nitrate) pour stockage

(3h → 16h en Espagne)



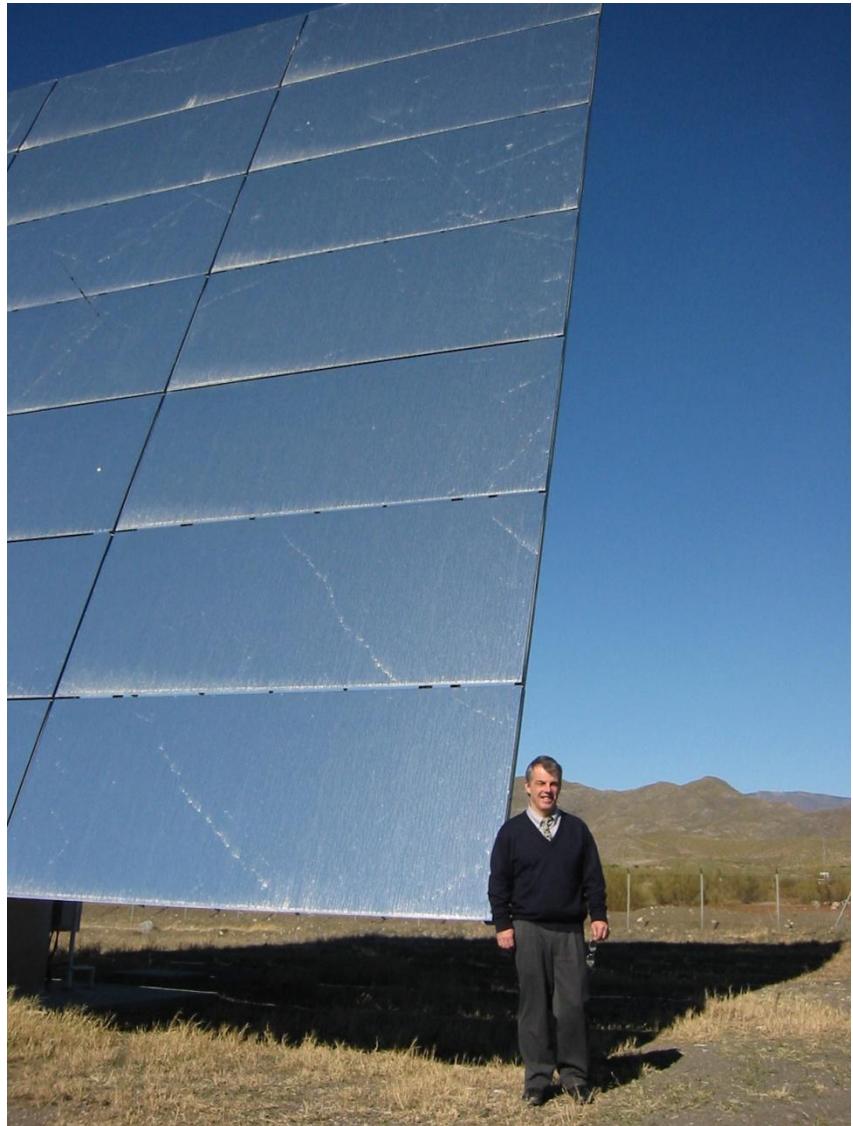
35 MW Thermiques

10 MW électriques r=28%



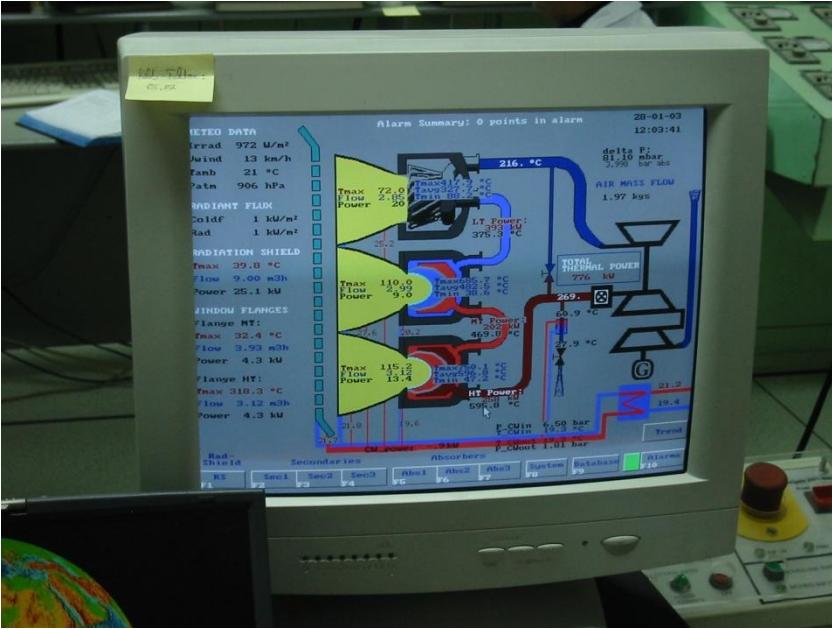
[http://www.outilssolaires.com/pv/prin-
centraleB.htm](http://www.outilssolaires.com/pv/prin-centraleB.htm)

Almeria



Espagne

Tarif de rachat: 2002 (premier pays Européen)
200 MW prévus en 2010





PS10 Première centrale commerciale (par Abengoa, Séville, Espagne)



624 héliostats

70 hectares

624 héliostats de 121 m² chacun (7,5 hectares)

Tour de 115 m T à 600-1000°C pour vapeur à 250°C à 40 bars

35 Millions d'Euros d'investissement

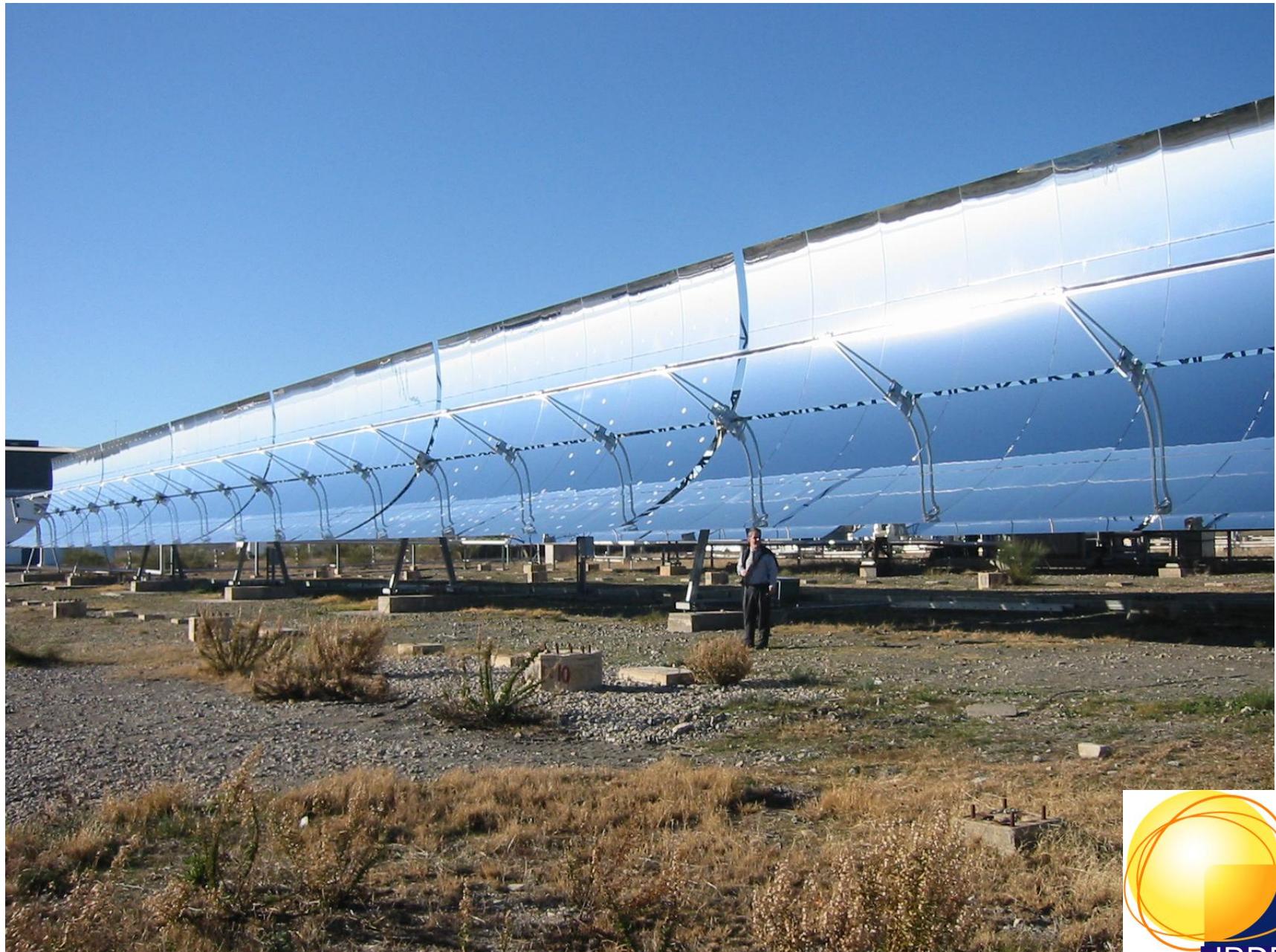
11 MW pour 23 GWh/an (146 W/m² soit 14,6 % de rendement électrique
, capacité 2100 h soit 24%)

Prévision : 301 MW en 2013

Approvisionnement de 180 000 foyers en électricité (Équivalent de Séville)

[http://www.outilssolaires.com/pv/prin-
centraleB.htm](http://www.outilssolaires.com/pv/prin-centraleB.htm)







La plus grande centrale solaire thermique au monde : Kramer Junction en Californie

5 unités de 30 MW soit 150 MW

Total de 354 MW de CST en Californie, raccordées au réseau



Concept Luz (1980)
Tubes fournis par RE Schott Solar

[http://www.outilssolaires.com/pv/prin-
centraleA.htm](http://www.outilssolaires.com/pv/prin-centraleA.htm)



Concentration dans les tuyaux 30 à 100
Fluide : huile synthétique à 400°C



Centrales à capteurs paraboliques

Couplage Disque-moteur stirling

Facteurs de concentration > 2000

Température : 700°C

Recherches depuis 30 ans



Californie : Centrales de 300 -900 MW prévues
(12 000 à 36 000 capteurs)

En février 2008, record mondial de rendement énergétique à partir d'un moteur Stirling alimenté à l'énergie solaire, soit 31,25%.





MW installed annually

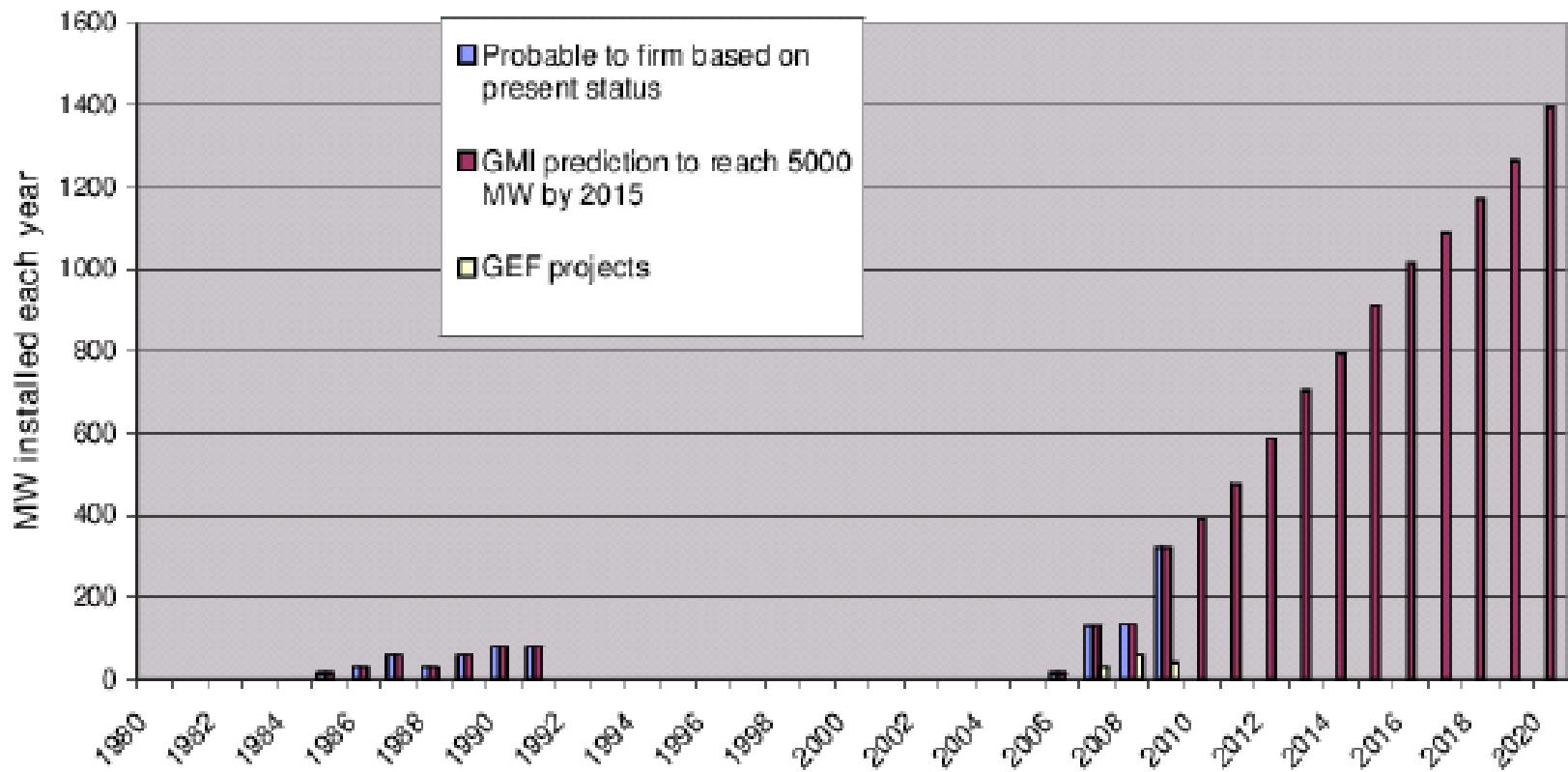
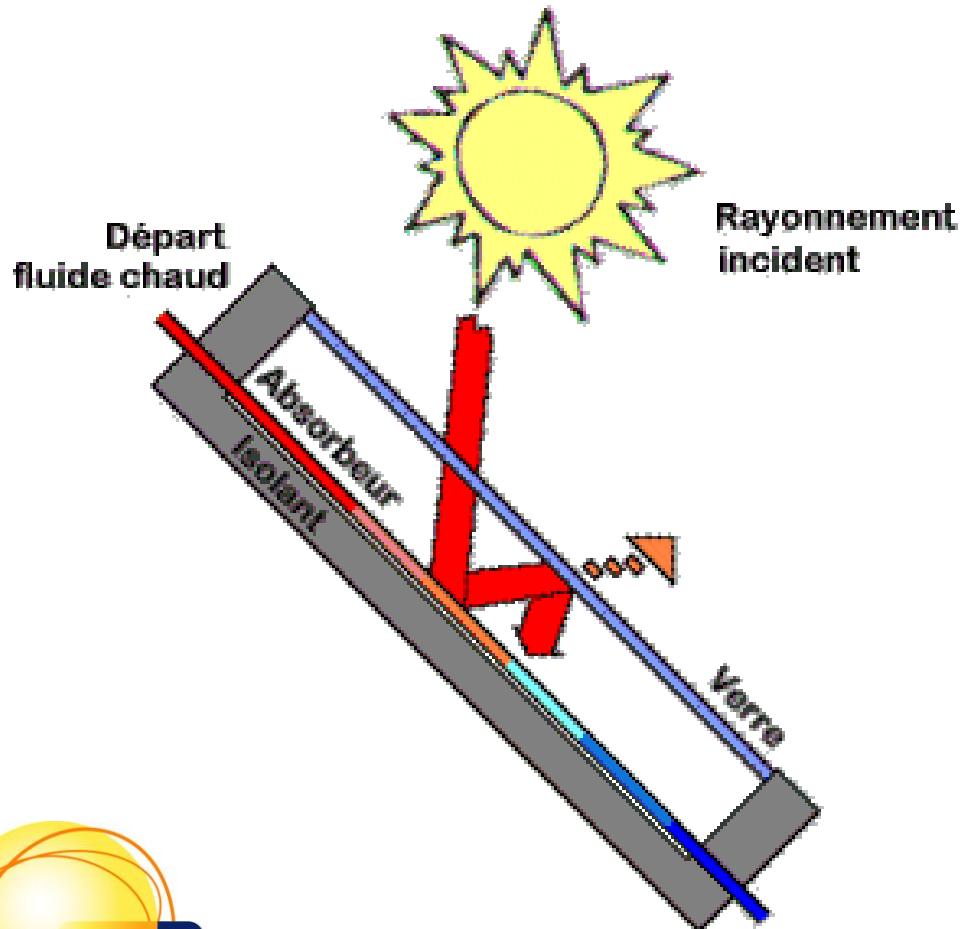
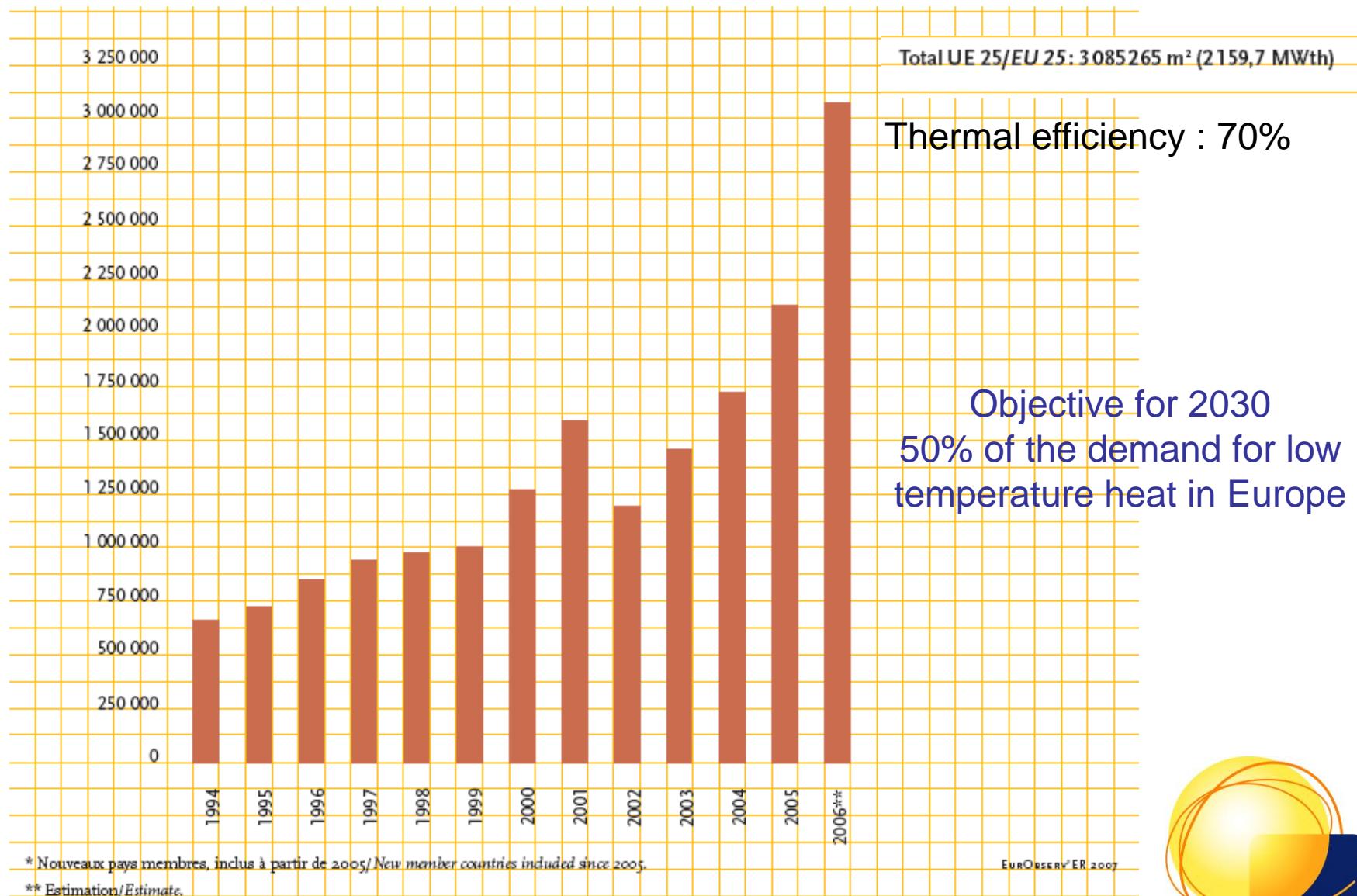


Figure 24: Puissance installée annuellement

Le chauffage solaire



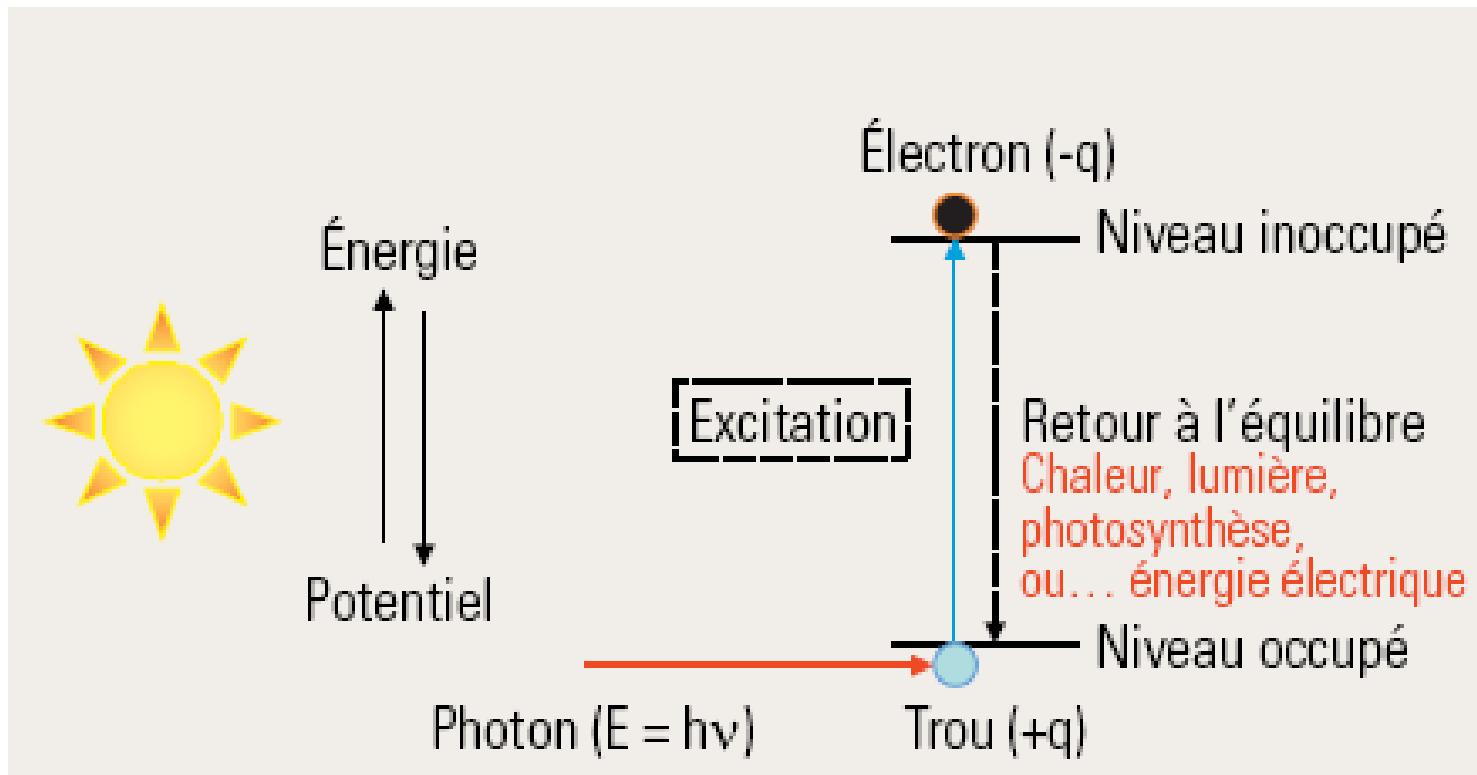
G1 ÉVOLUTION DES SURFACES INSTALLÉES DANS L'UNION EUROPÉENNE DEPUIS 1994* (EN M²)
EVOLUTION OF ANNUALLY INSTALLED SURFACES IN THE EUROPEAN UNION SINCE 1994 *(IN M²)



EuroObserv'ER 2007



L'énergie solaire photovoltaïque

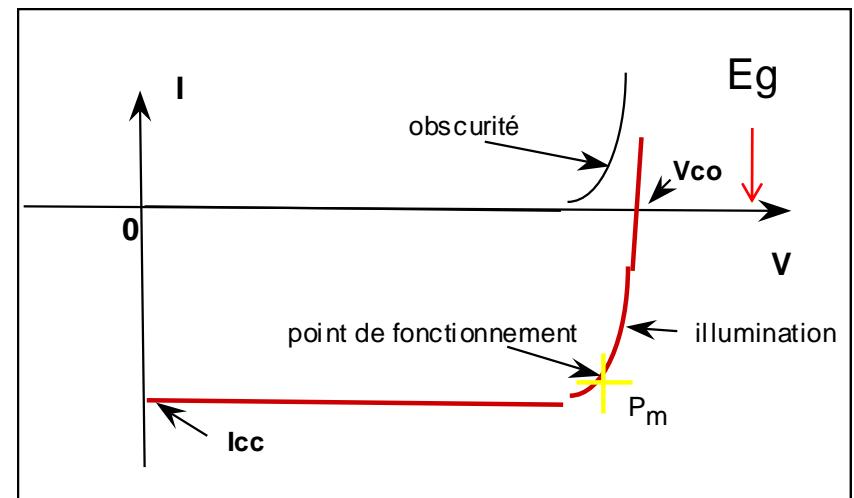
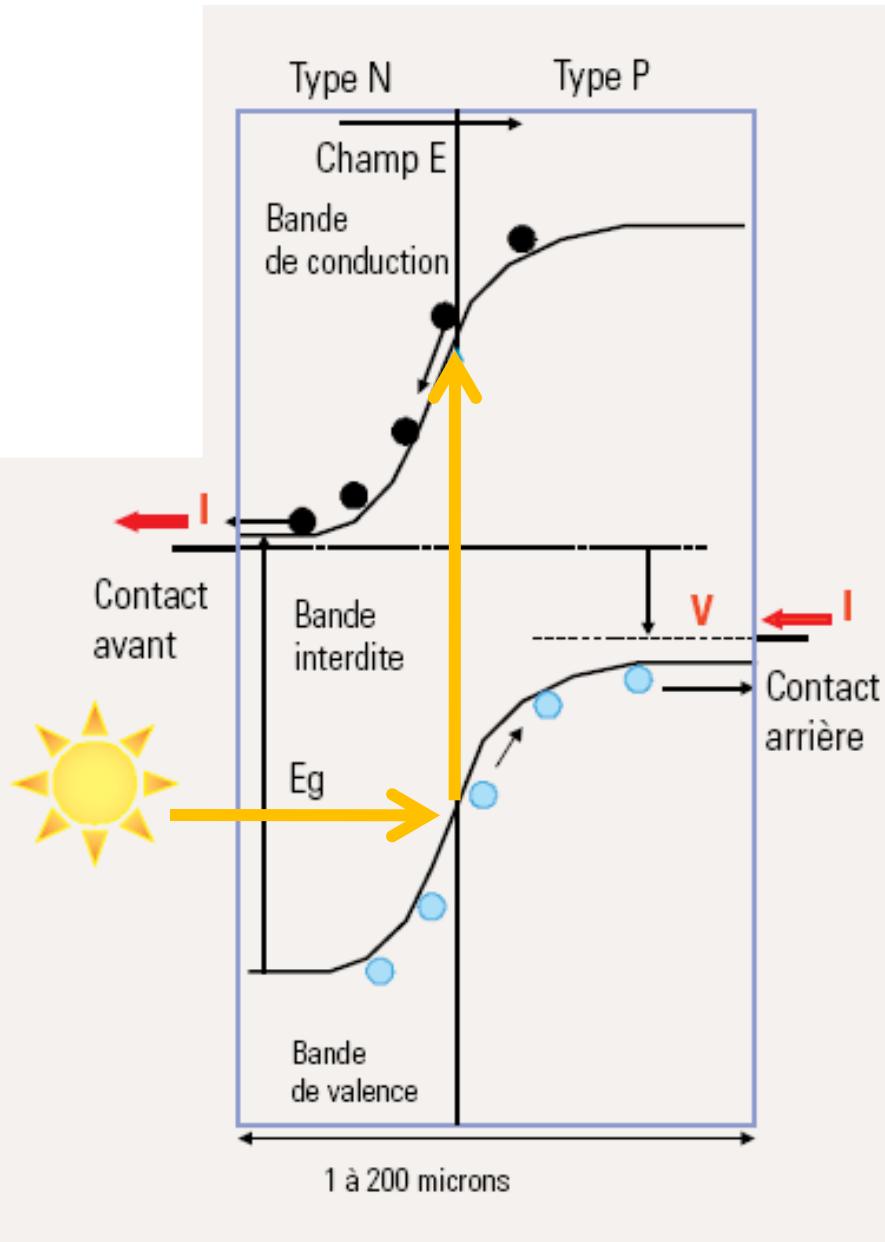


La Filière Silicium cristallin et polycristallin « silicium massif » 88 % du marché

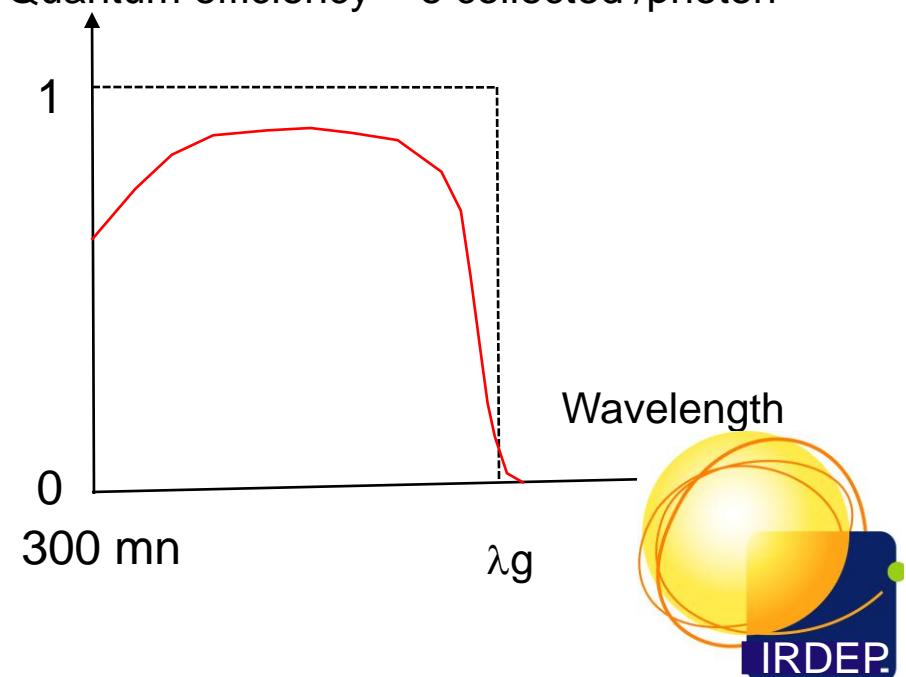
Labo : 24,7 % monocristallin
20 % polycristallin

Modules : 14- 20% Mono
12-14% poly

P doped Si B doped Si



Quantum efficiency = e collected / photon



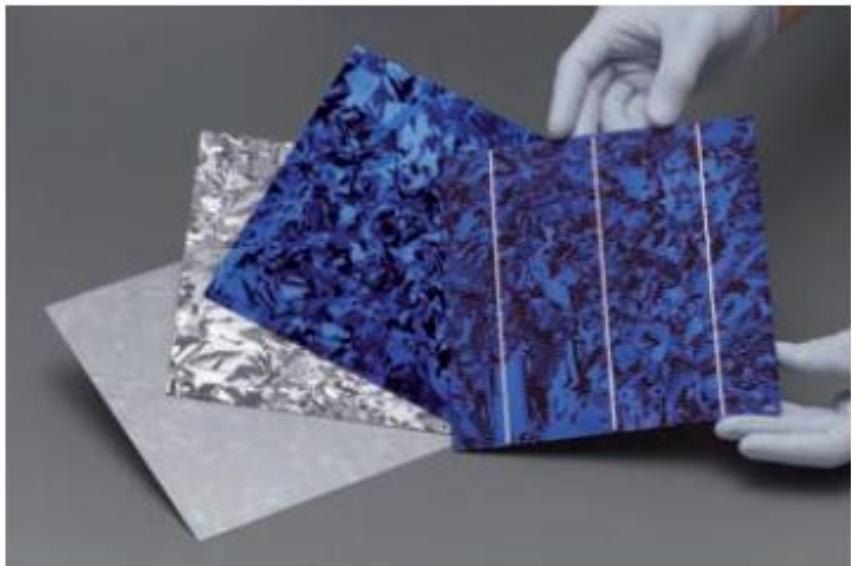


FIGURE 8

Cellule photovoltaïque silicium 20 cm × 20 cm.

Rendement de conversion 14,75 %

De gauche à droite : plaque Si après découpe, après texturation, après formation de la jonction et dépôt du traitement anti-réfléchissant et cellule finie.

© CEA, plate-forme RESTAURE cofinancée par l'ADEME.

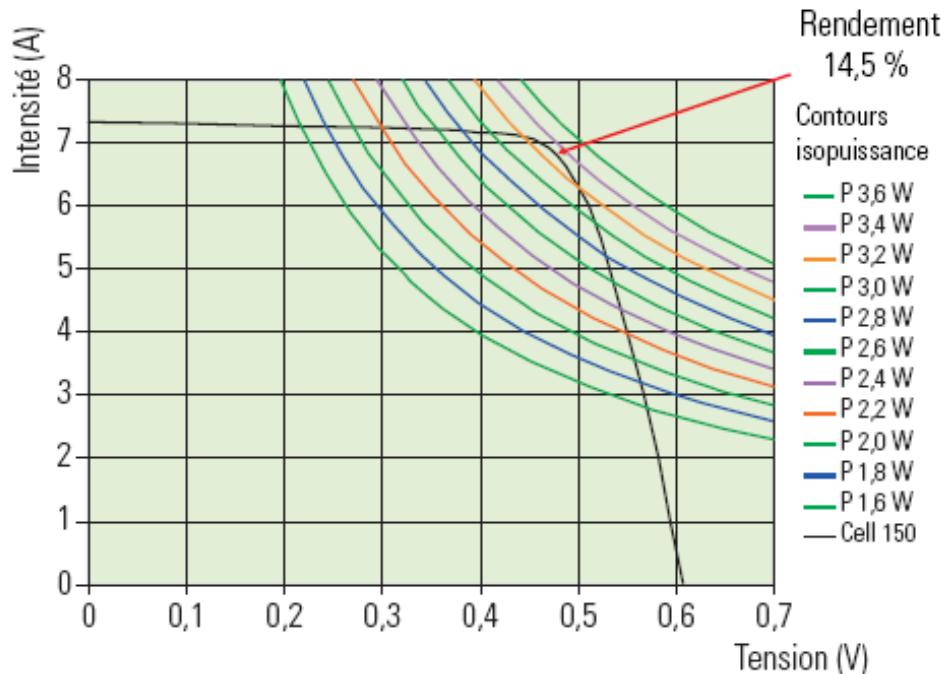


FIGURE 7

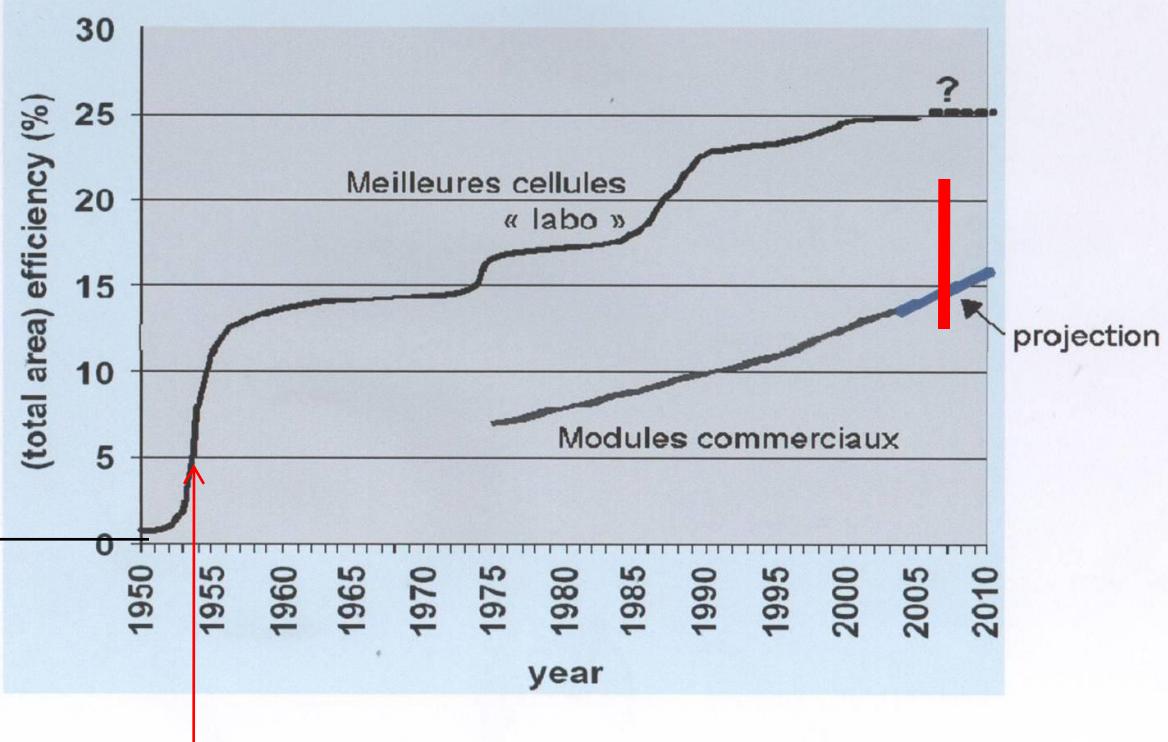
Caractéristique courant-tension d'une cellule solaire commerciale au silicium polycristallin

(15 cm x 15 cm de 0,2 mm d'épaisseur)
sous éclairement solaire normalisé 1 000 W/m².

© Photowatt International S.A.



Cellules de laboratoire & industrielles



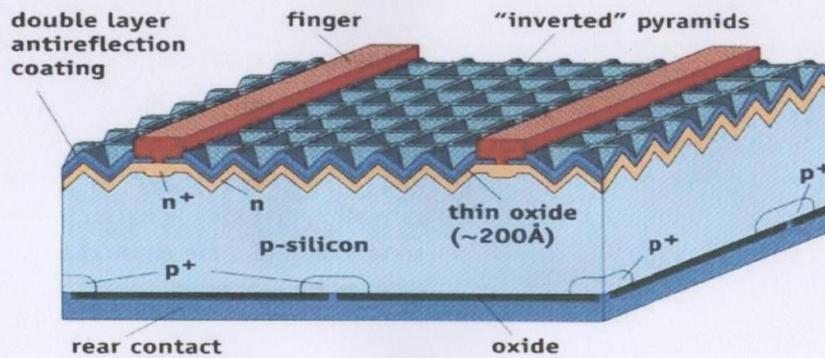
1839 E. Becquerel
Le découvreur
1877 W.G. Adams & R.E. Day
Cellules Se 1%

Chapin & Fuller & Person
Si(6%)



Source : J.C. Muller

Cellule au silicium de rendement record



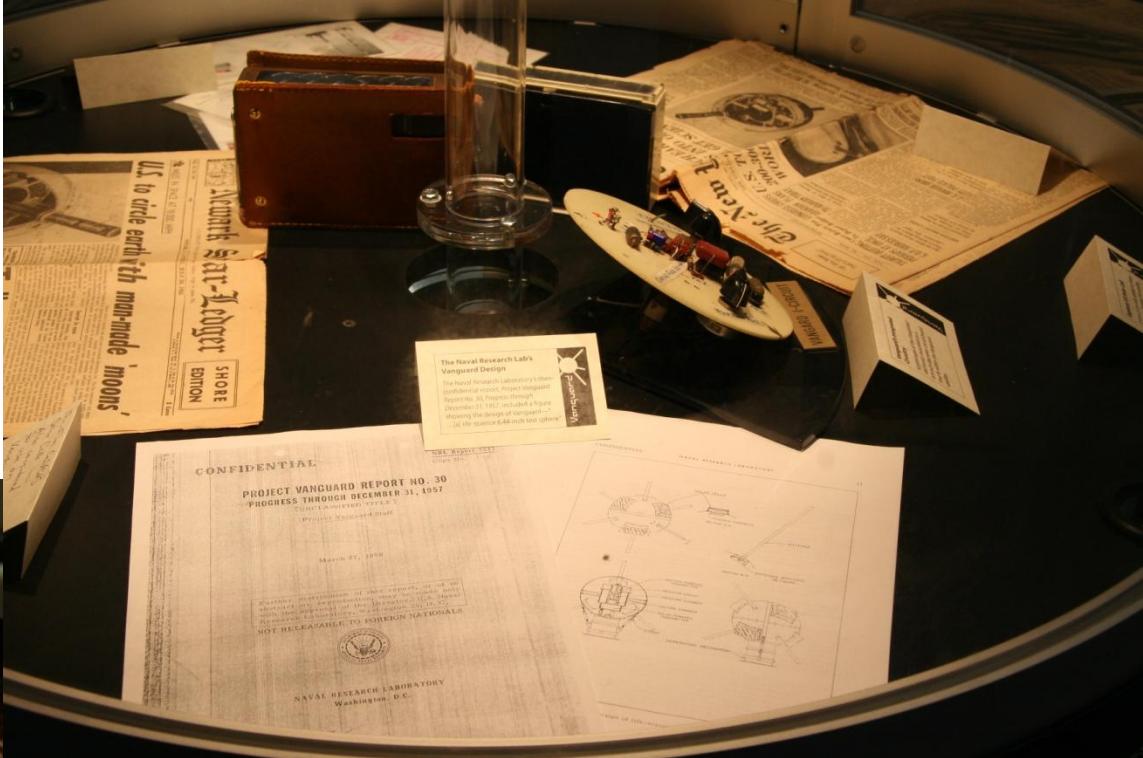
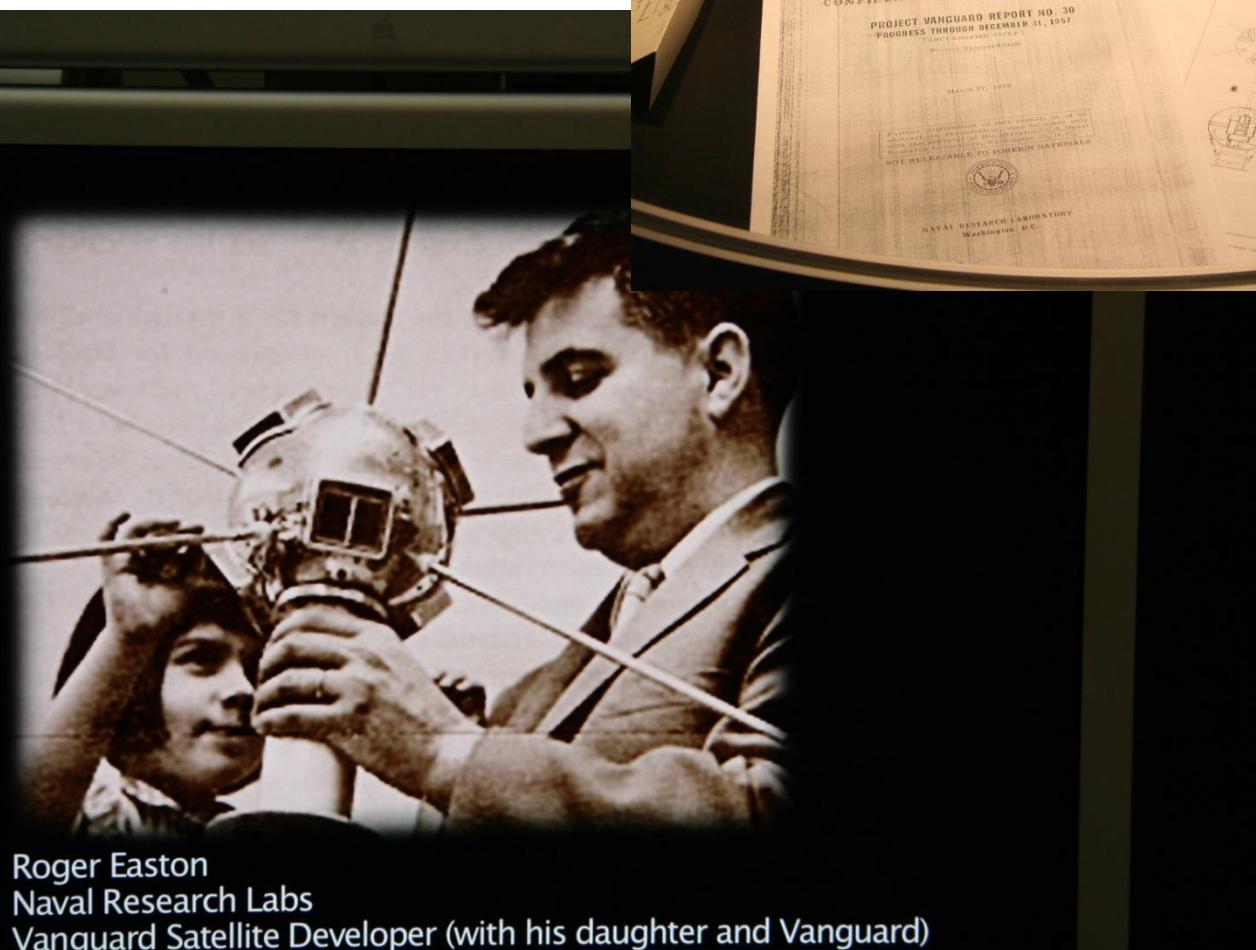
$$I_{cc} = 42,2 \text{ mA/cm}^2 ; V_{co} = 0,706 \text{ Volt} ; \eta_P = 24,7 \%$$

Cellule PEARL M. Green et al UNSW (Australie)

Source : J. C. Muller

Premier Satellite Alimenté par des cellules photovoltaïques

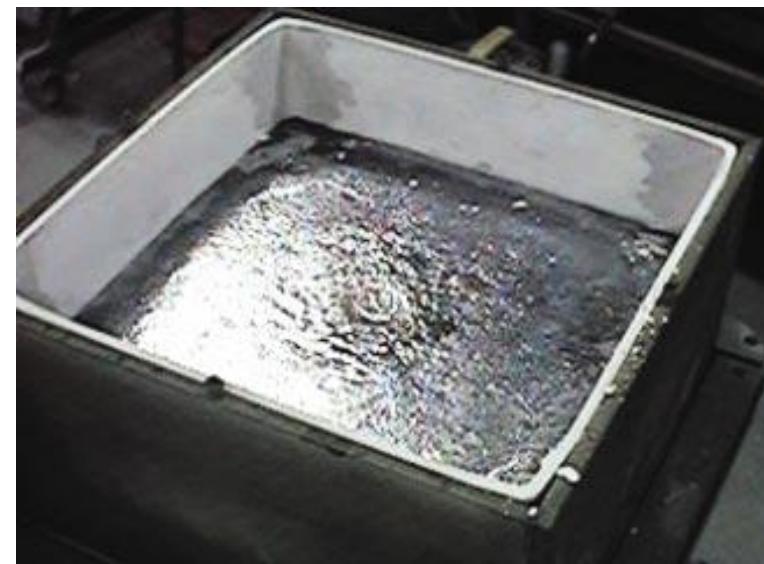
Vanguard, USA, 1958



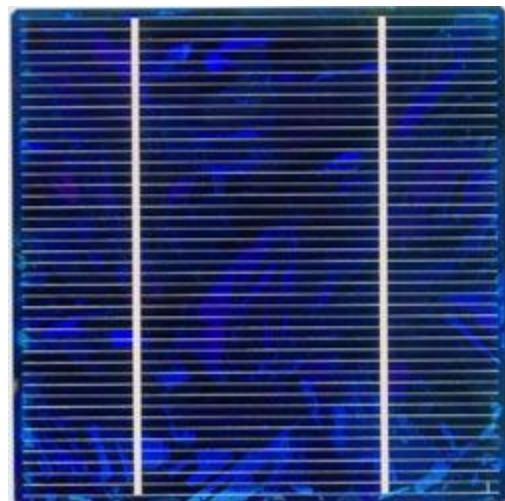
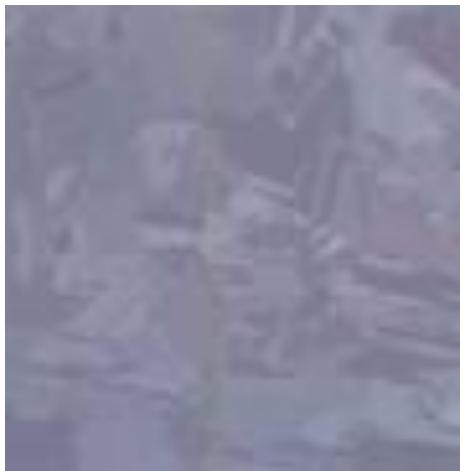
Photos:
J. Wanegue



D. Lincot SLC –Autrans –Oct. 2009



Source : Photowatt



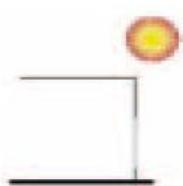
Source : Photowatt

D. Lincot SLC –Autrans –Oct. 2009

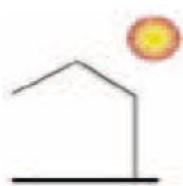


Source : Photowatt

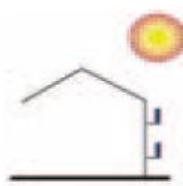
L'intégration au bâtiment



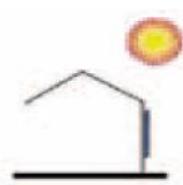
Pose en allèges



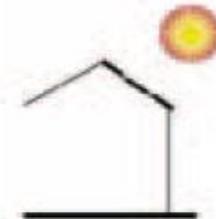
Pose en verrière
sans protection arrière



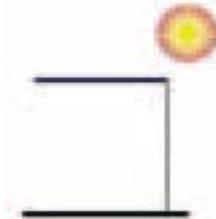
Pose en garde-corps de fenêtre,
de balcon ou de terrasse



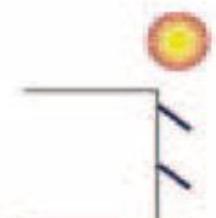
Pose en bardages, mur rideau



Pose en toiture inclinée
(tuiles, ardoises,...)



Pose en toiture terrasse
(membrane étanche)



Pose en brise soleil



La centrale de Pocking (Allemagne)

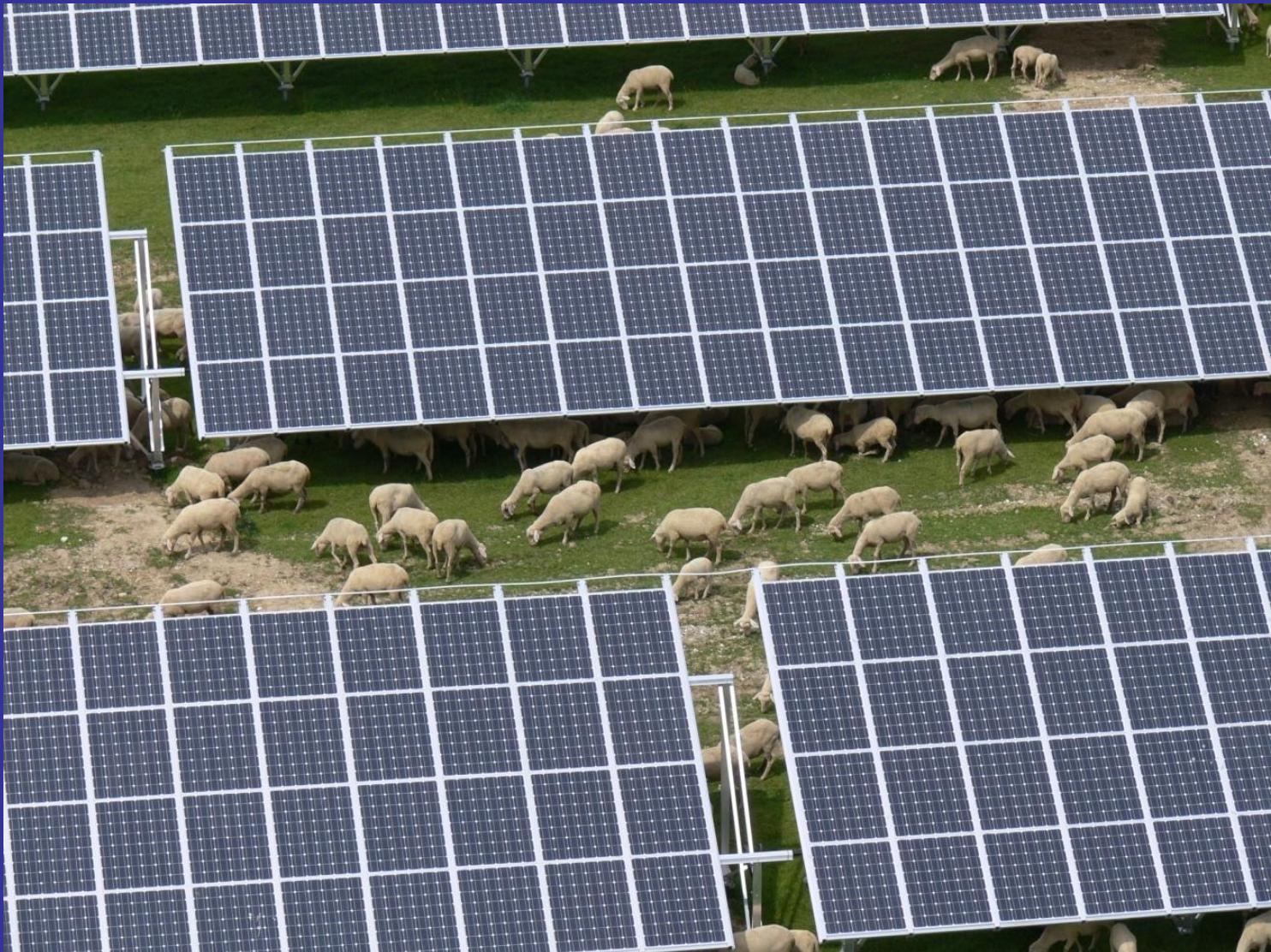
10 MWc

Alimentation de 3300 maisons

Actuellement 60 MWc

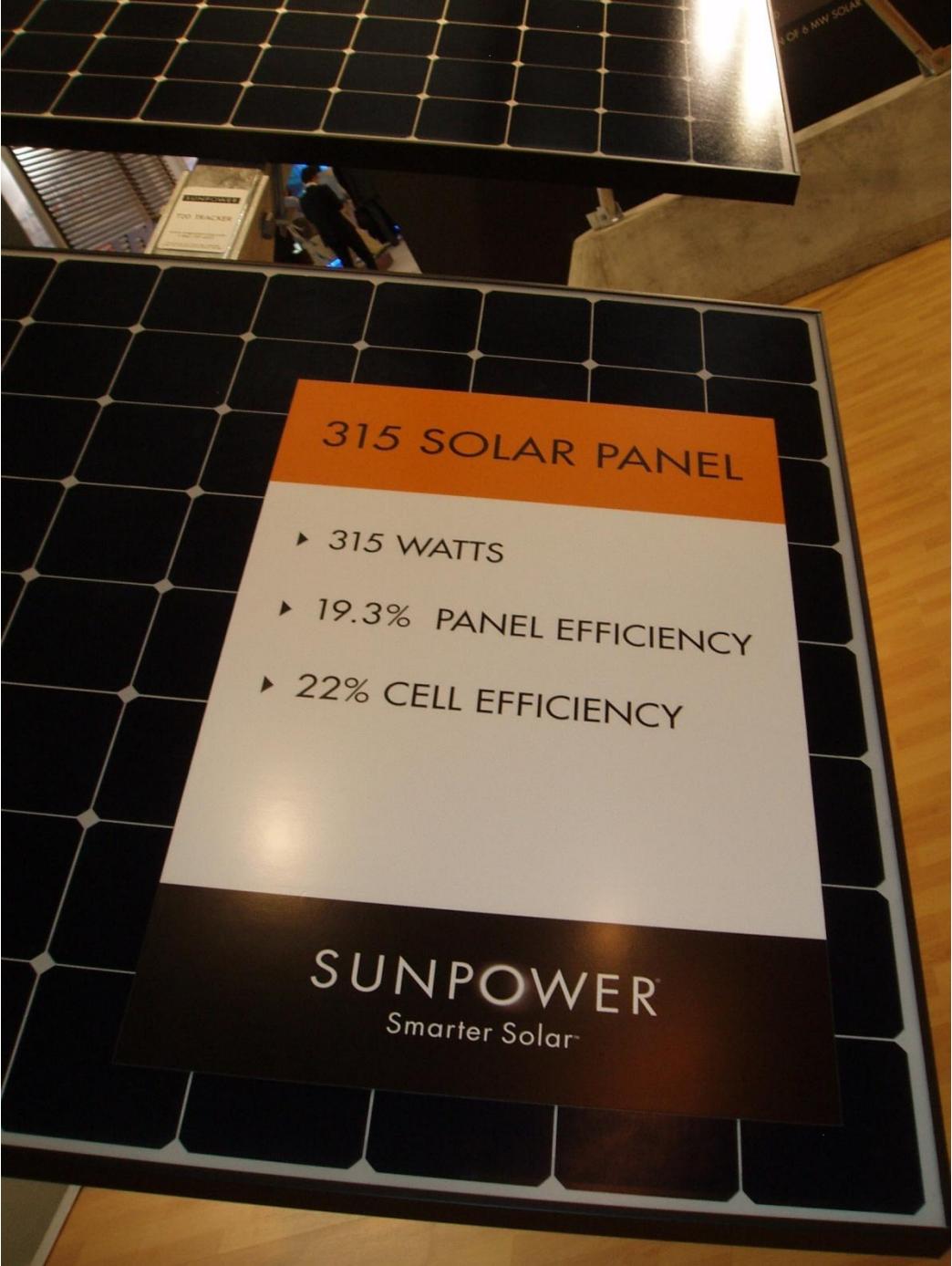


Les centrales photovoltaïques au sol (1ha → 1 MWc → 1-1,5 GWh/an)

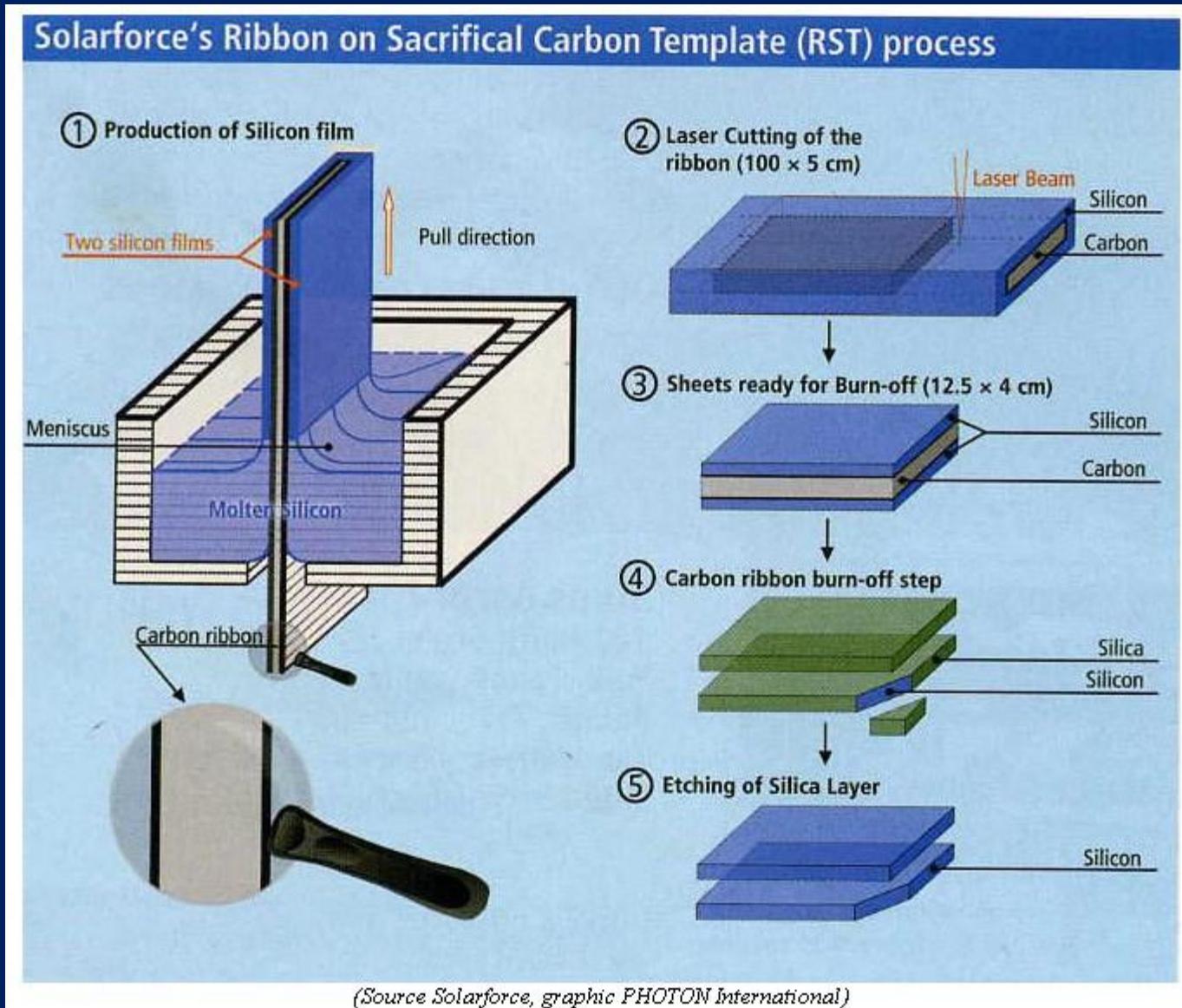


Autres tendances :

Tranches fines (100 microns)
Découpe Laser



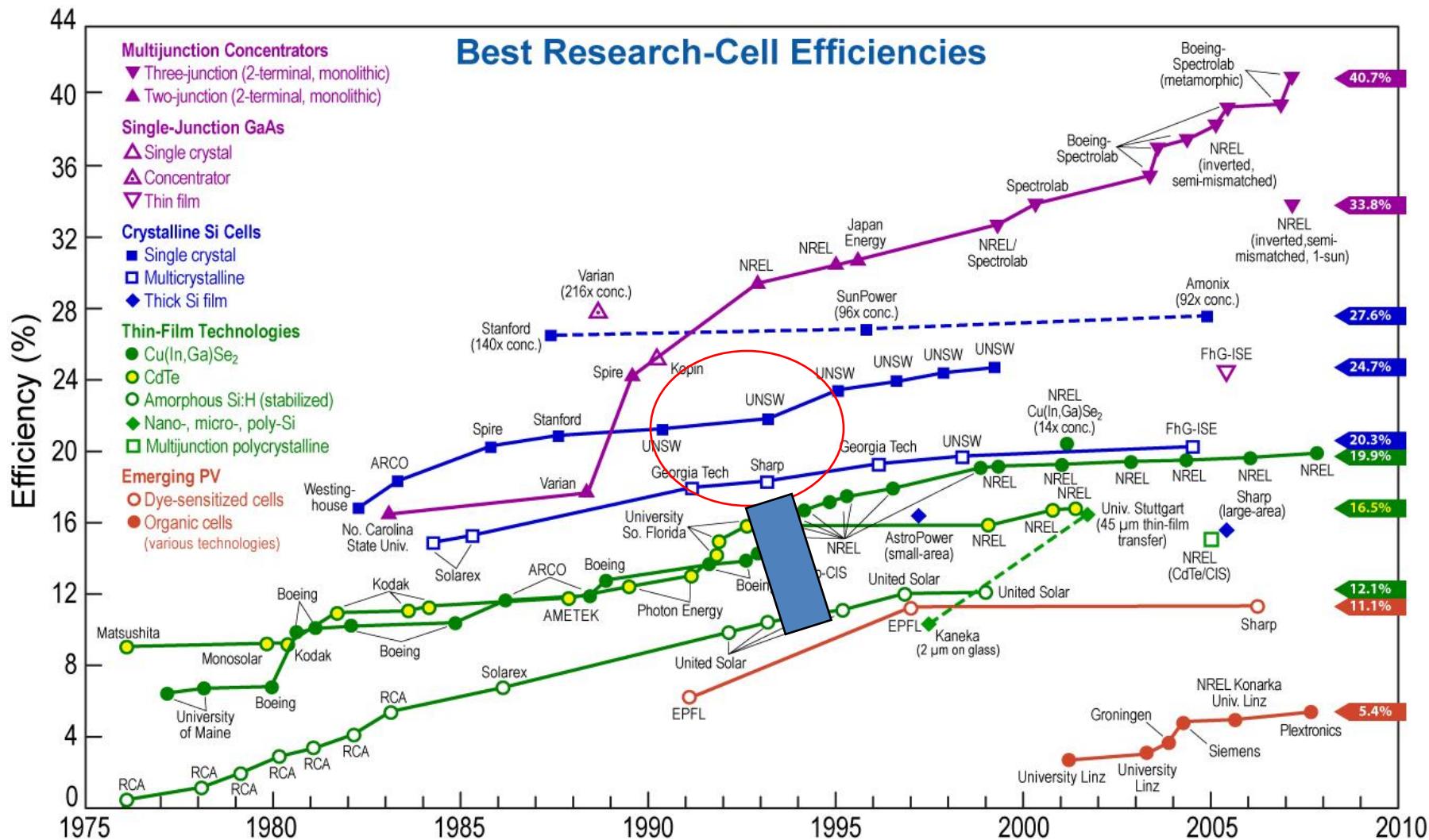
Procédés sans découpe : Silicium Ruban



Procédés sans découpe : Silicium Ruban



Source : J. Amouroux



Source NREL

Les filières « couches minces »

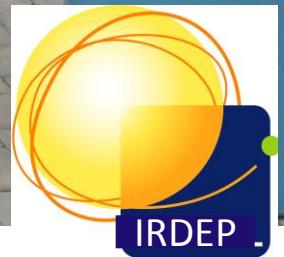
12% du marché

Silicium : 13% max 6-9 % modules)

Tellurure de cadmium (CdTe) : 16,5 % max 10-11% mod

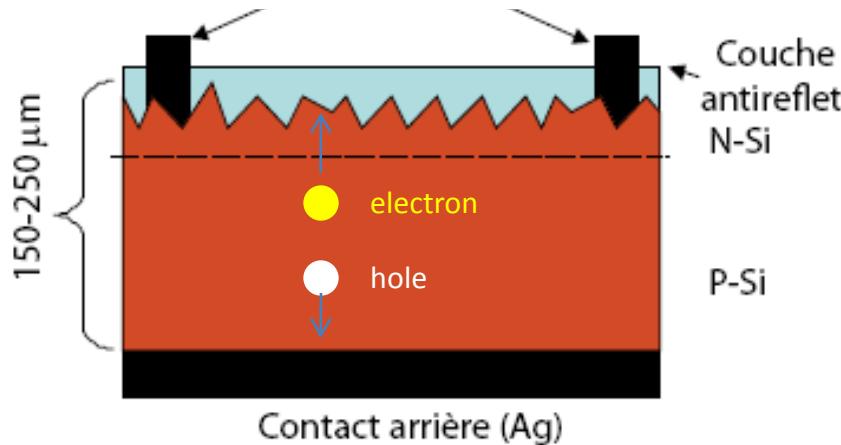
Diseleniure de cuivre et d'indium (CIS) : 20% max 10-14% mod

European Photovoltaic Solar Energy (Valencia) 2008

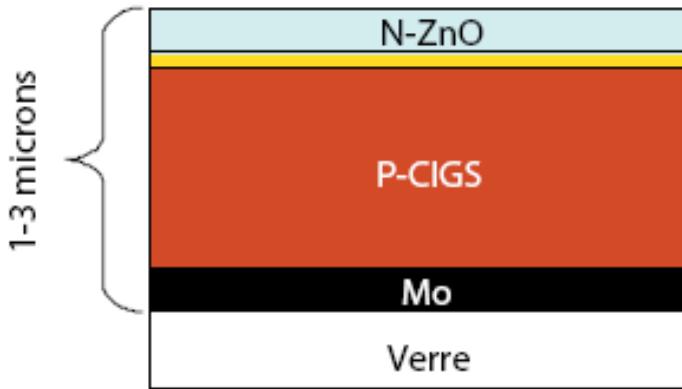




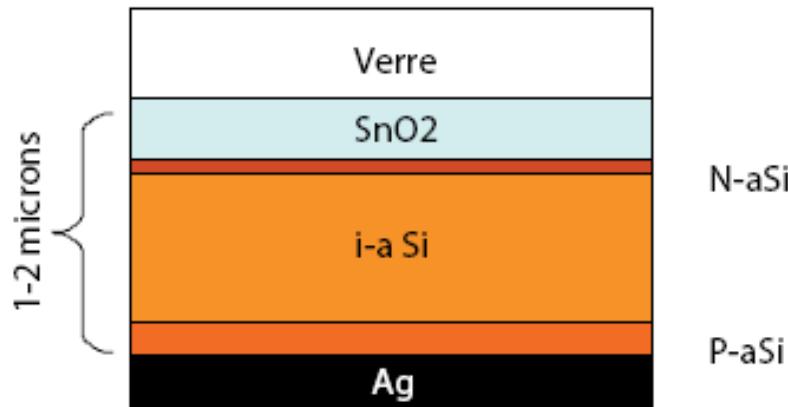
Cristalline silicon (cSi)



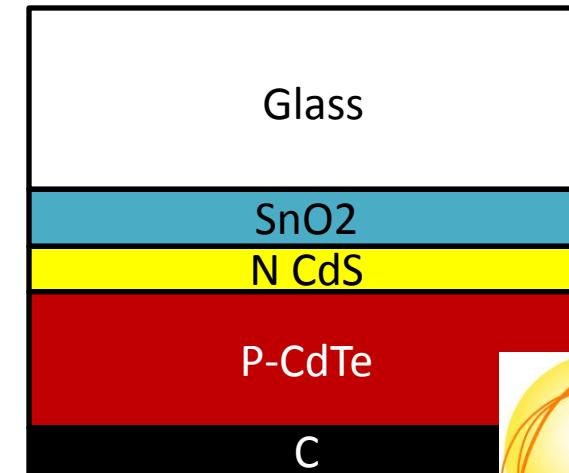
Copper Indium gallium diselenide (CIGS)



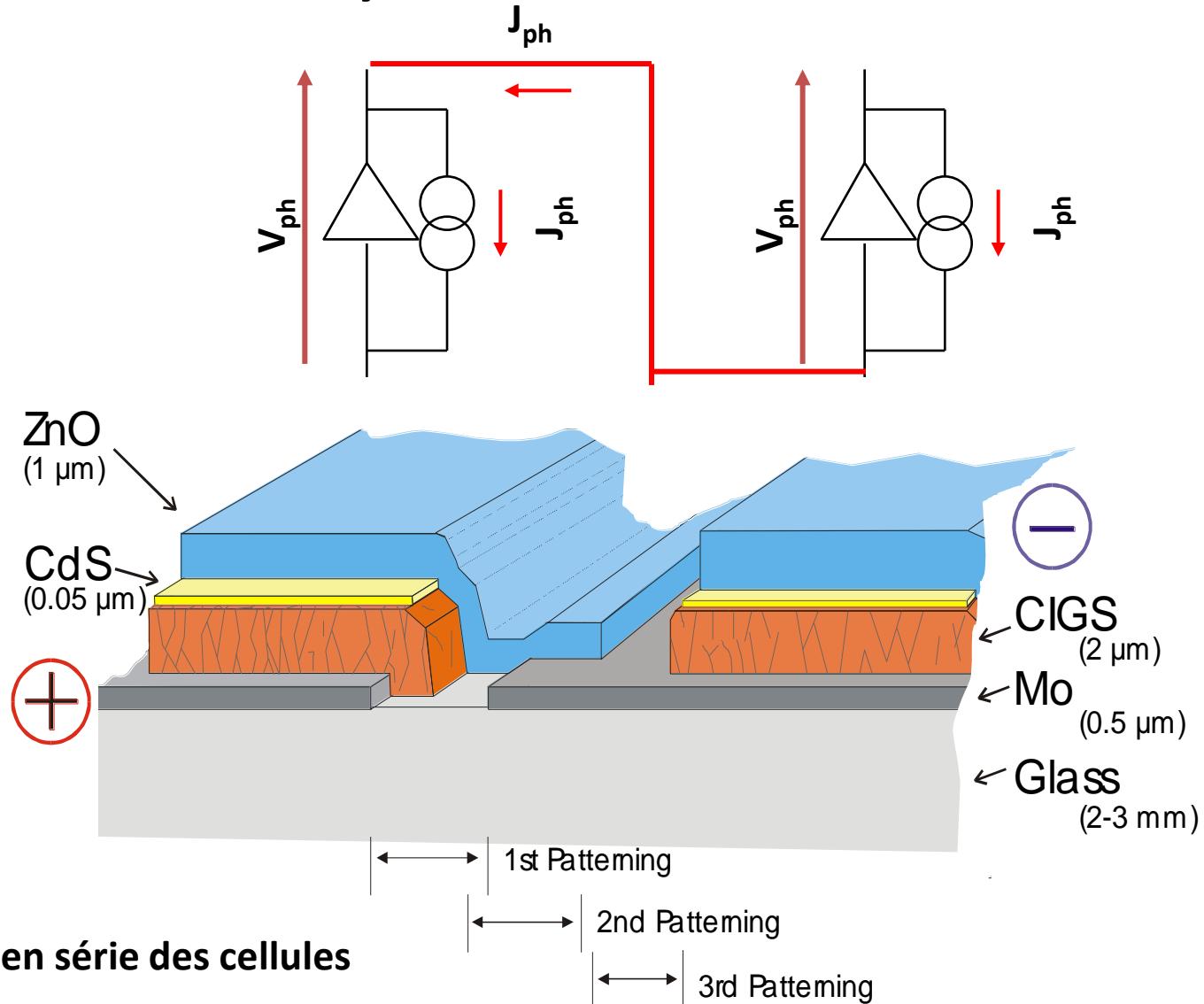
Amorphous silicon (aSi)



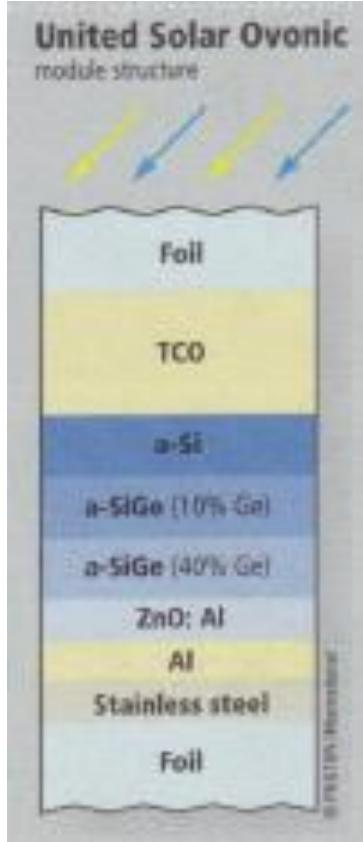
Cadmium telluride (CdTe)

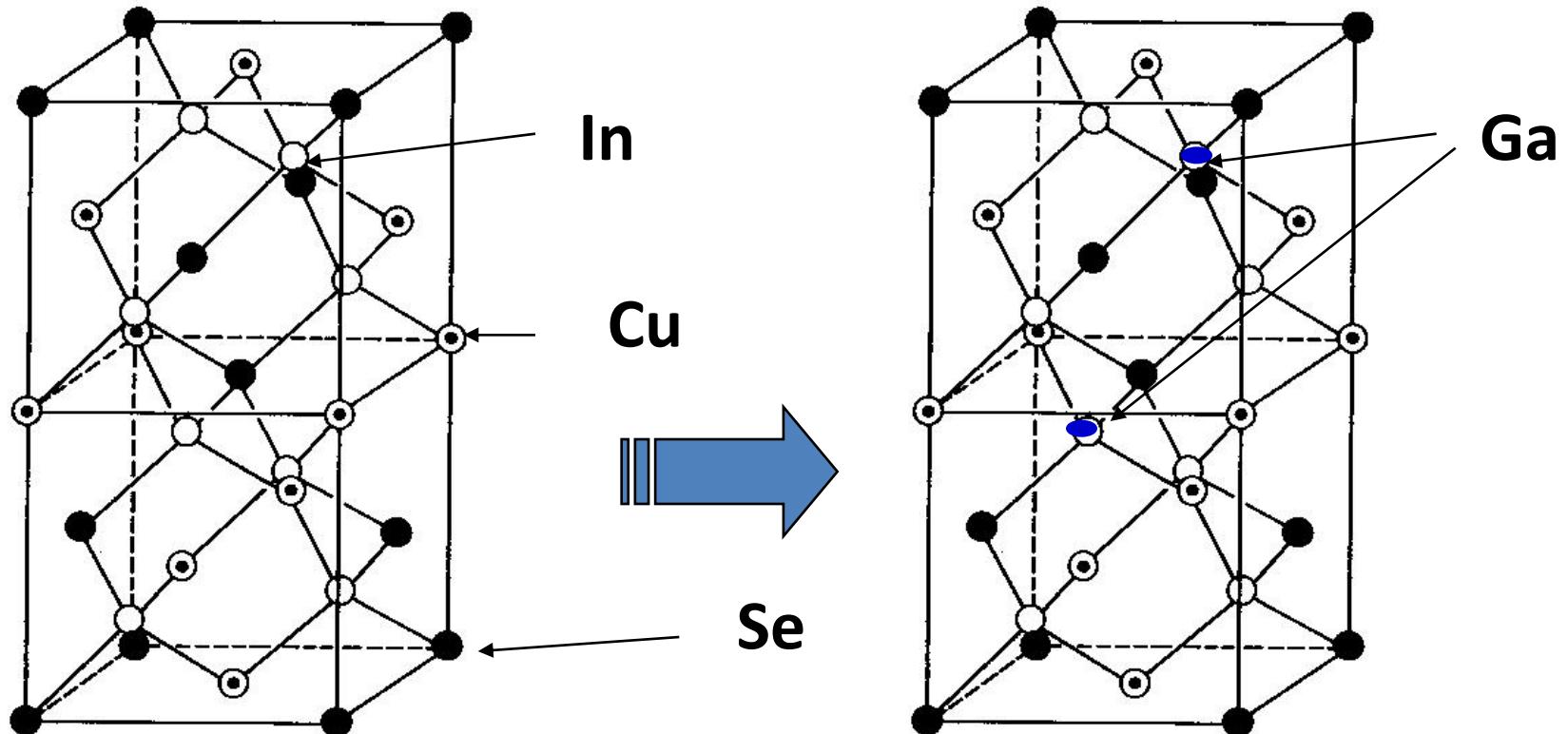


Monolytic Interconnection



Par Courtoisie : Dr. Hans W. Schock (IPE)





CuInSe_2

« CIS »

1 eV

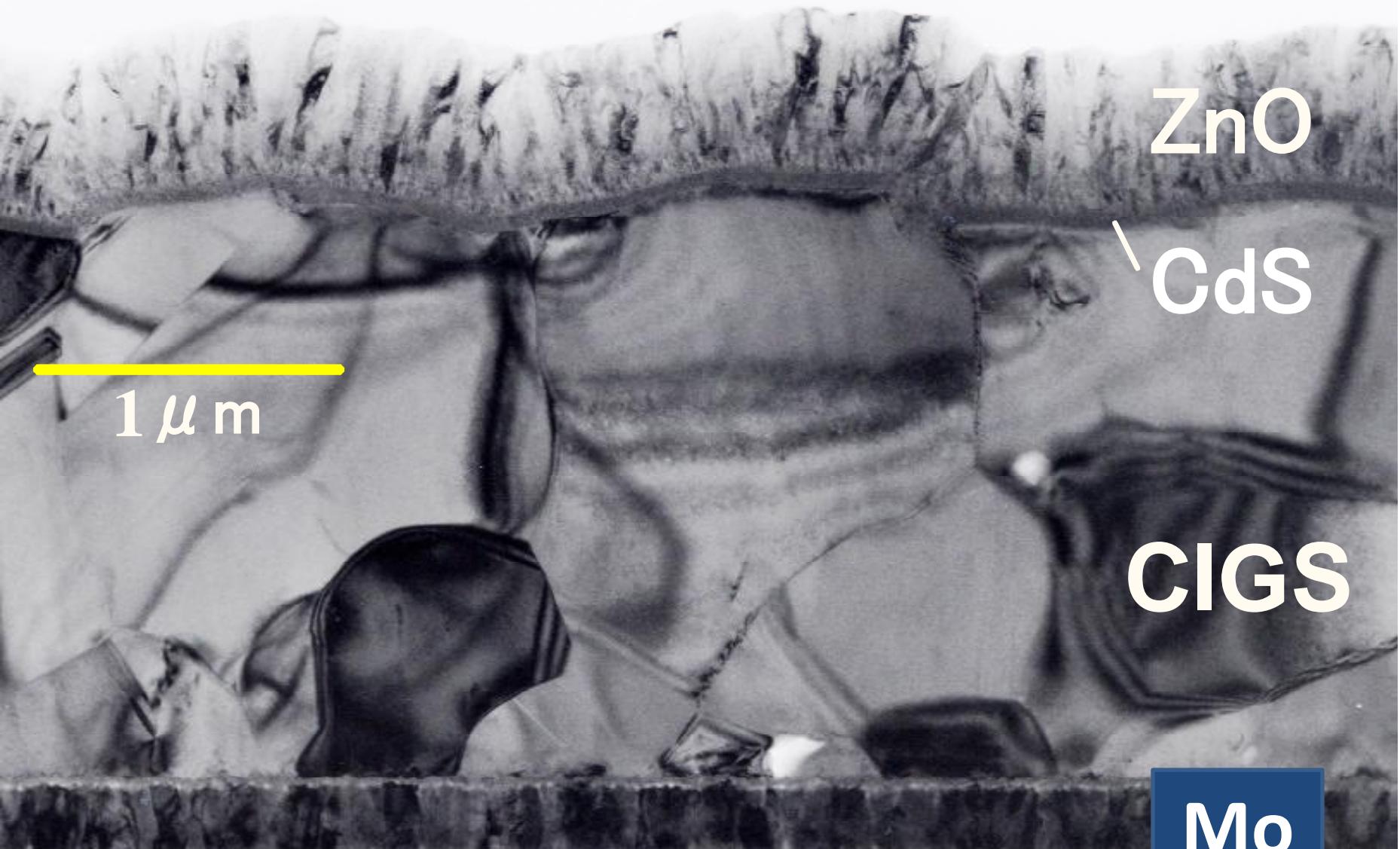
$\text{Cu}(\text{In},\text{Ga})\text{Se}_2$

1,15 eV

« CIGS »



Source : Prof Nakada



SLG
7

Mo

ZnO
\CdS

CIGS



First Solar



http://www.firstsolar.com/pdf/FS_brochure_FR.pdf

Example : 7 MW PV farm in France



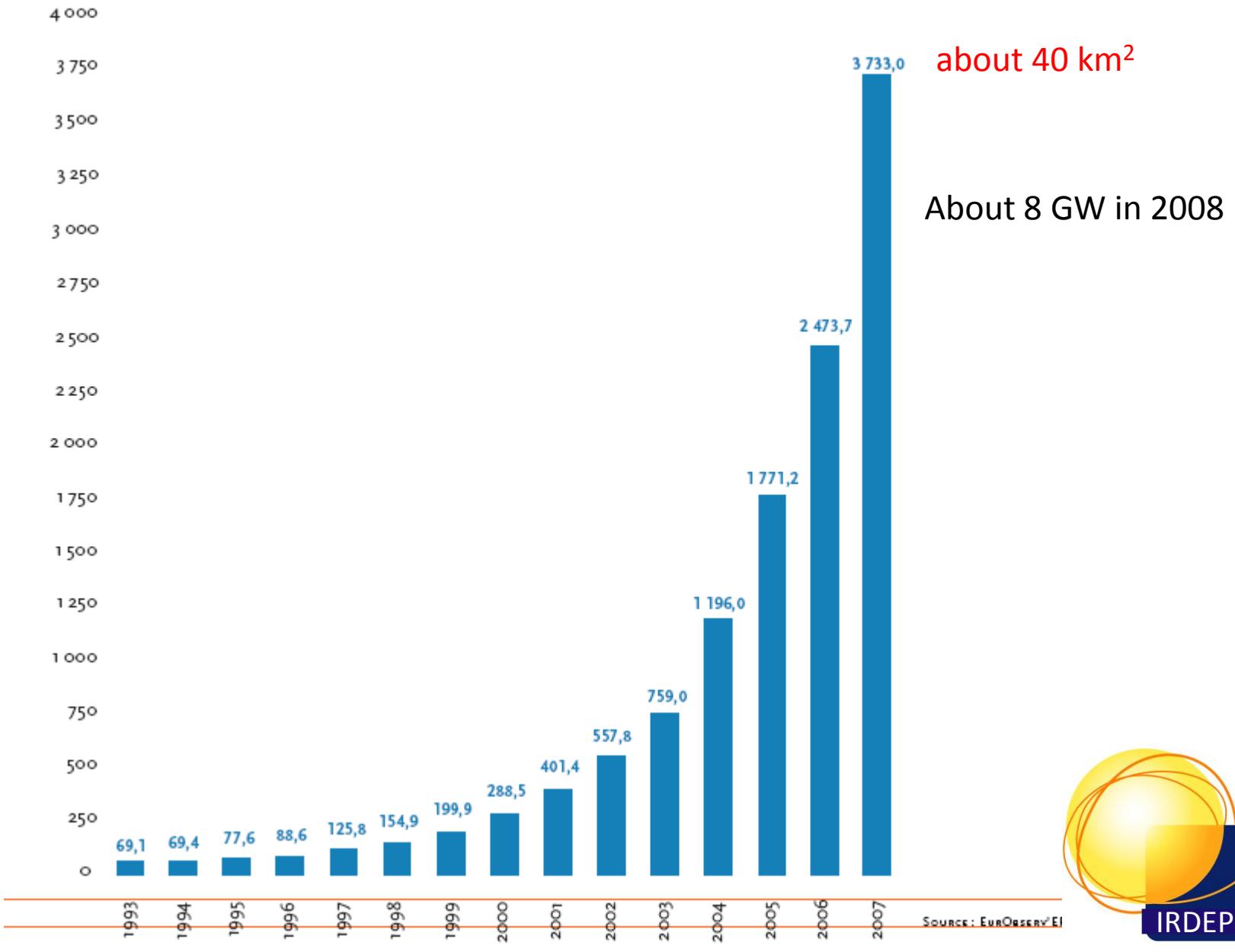
La maison Zen (Zero Energy Net) in Chambery of Alain Ricaud
Positive energy house in France <http://www.cythelia.fr>



PV System CIS (Sulfurcell) 13.5 kWp 12 000 kWh/year
for 9000 kWh/year consumption



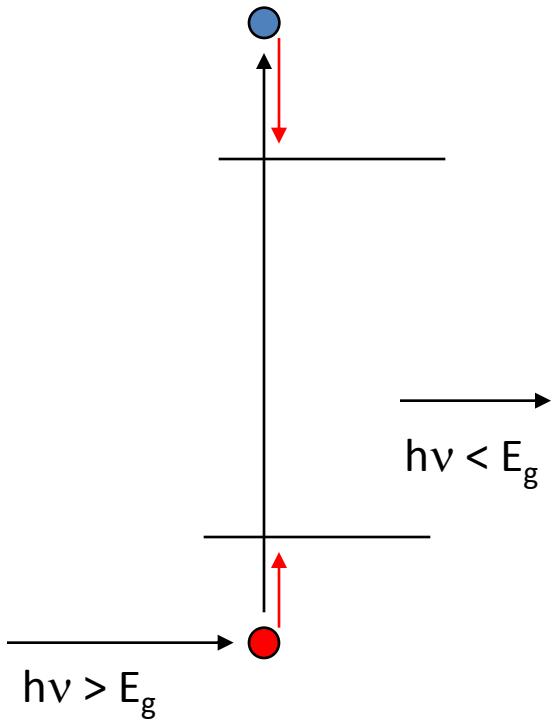
World Production of Photovoltaic Modules (MWp)



Year	Total Production(M W _c)	Annual Growth	Thin film solar cells(%)	A-Si based (%)	CdTe (%)	CIS (%)
1999	202		13,6	12,9	0,3	0,2
2000	287	42%	10,1	9,6	0,3	0,2
2001	401	40%	9,6	8,9	0,5	0,2
2002	560	39%	7,3	6,4	0,7	0,2
2003	750	34%	6,1	4,5	1,1	0,5
2004	1200	68%	6	4,4	1,1	0,5
2005	1800	45%	6,3	4,7	1,4	0,2
2006	2530	40%	7,6	4,7	2,7	0,2
2007	4280	69%	10	5,2	4,7	0,5
2008	7900	85%	12,5	5,1	6,4	1

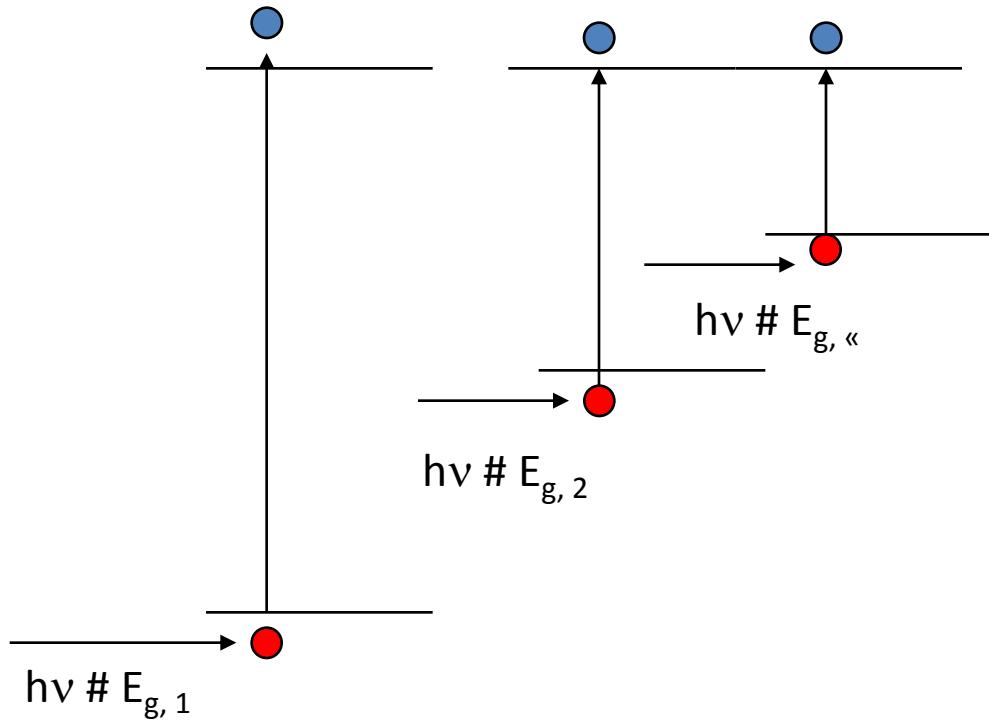
Source : Photon magazine 2009

Comment accroître le rendement de conversion ?



Rendement limite simple jonction 30%

Pertes par thermalisation
Pertes par non absorption

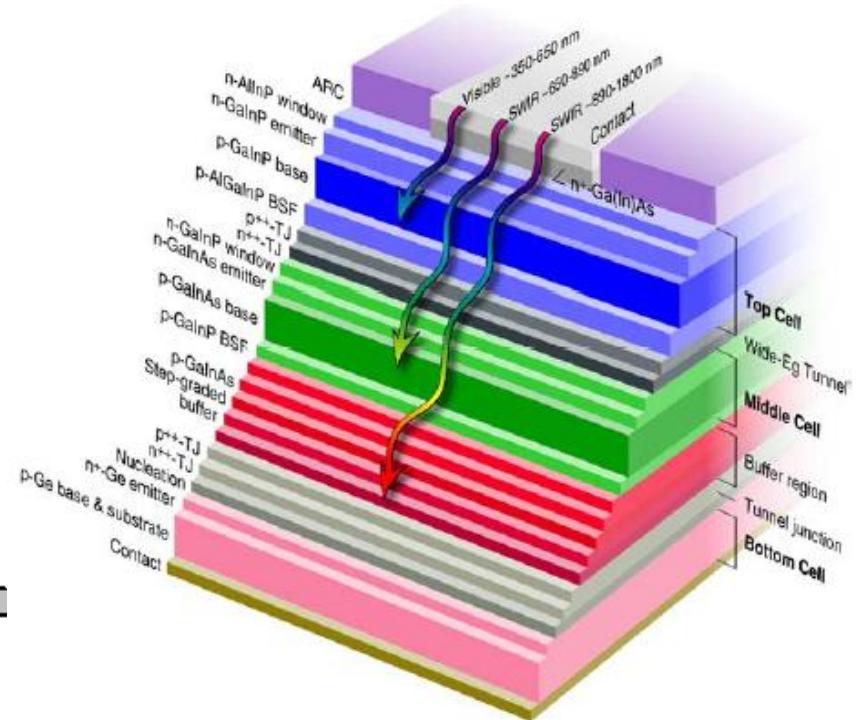
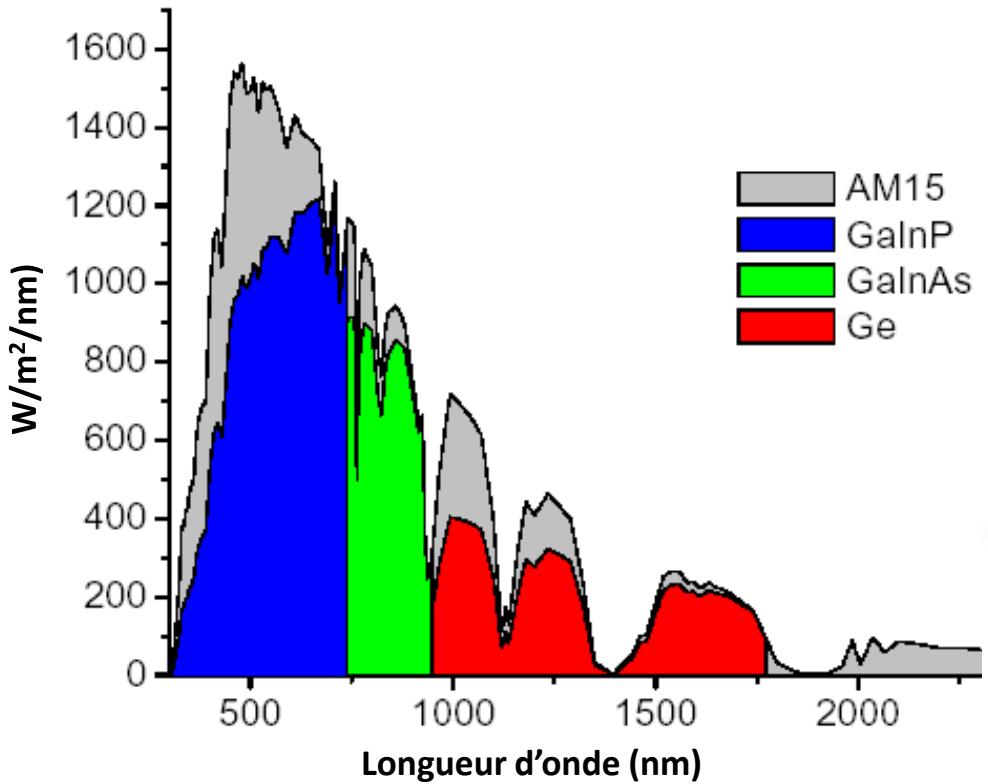


Rendement limite multijonctions 85 %

High Efficiency Multijunction concepts

State of the art

III-V Compounds and Si based



More than 40% under concentration (x 286)

Spectrolab

Very complex, very costly

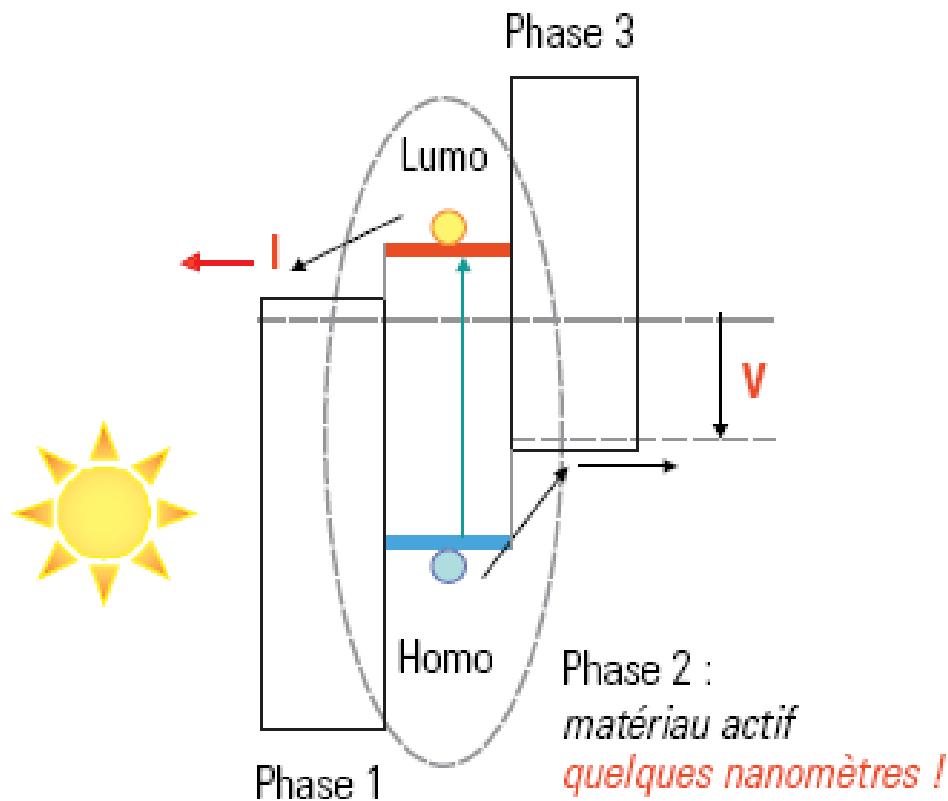


FIGURE 17
Approche nouvelle :
photovoltaïque moléculaire.

Les cellules nanocristallines à colorants

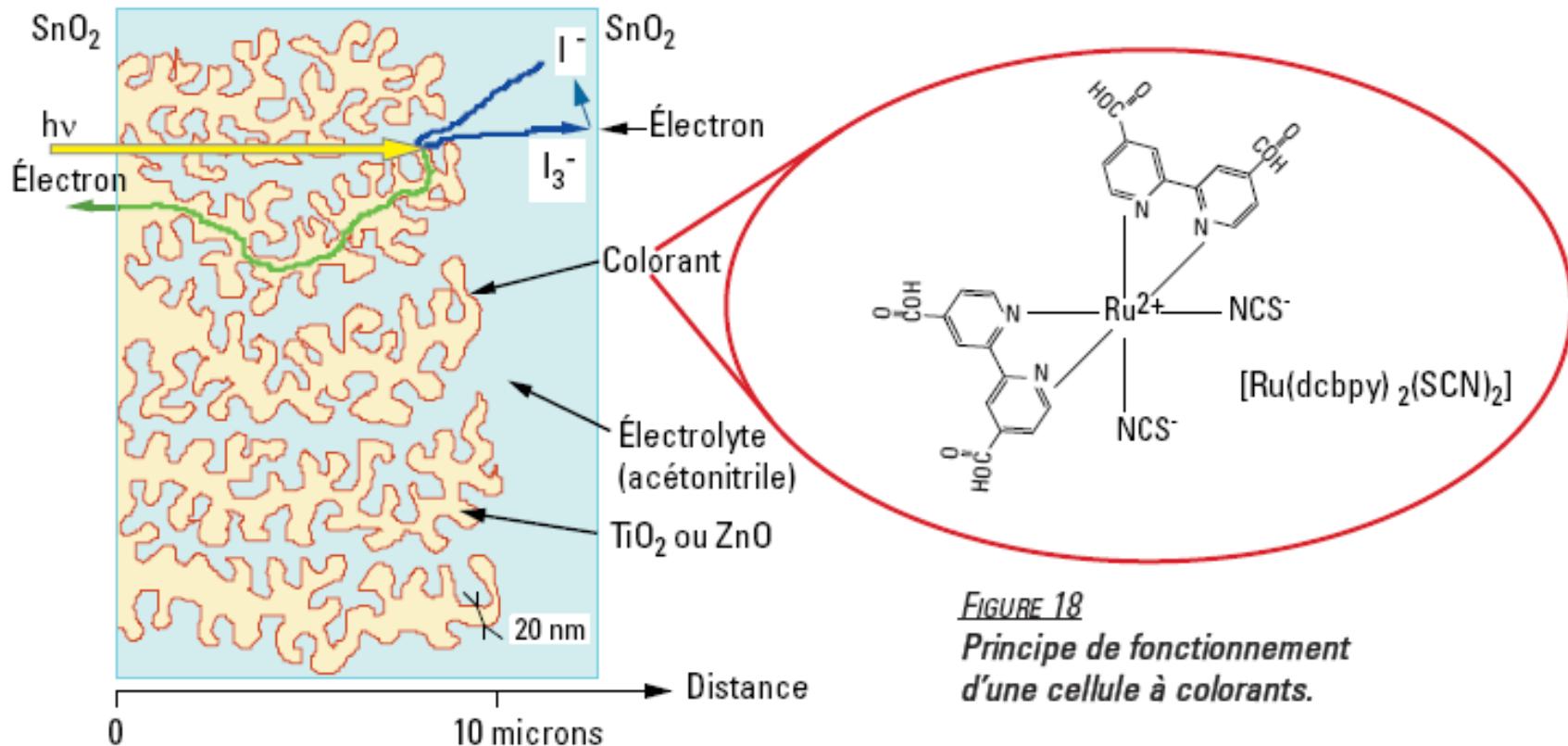
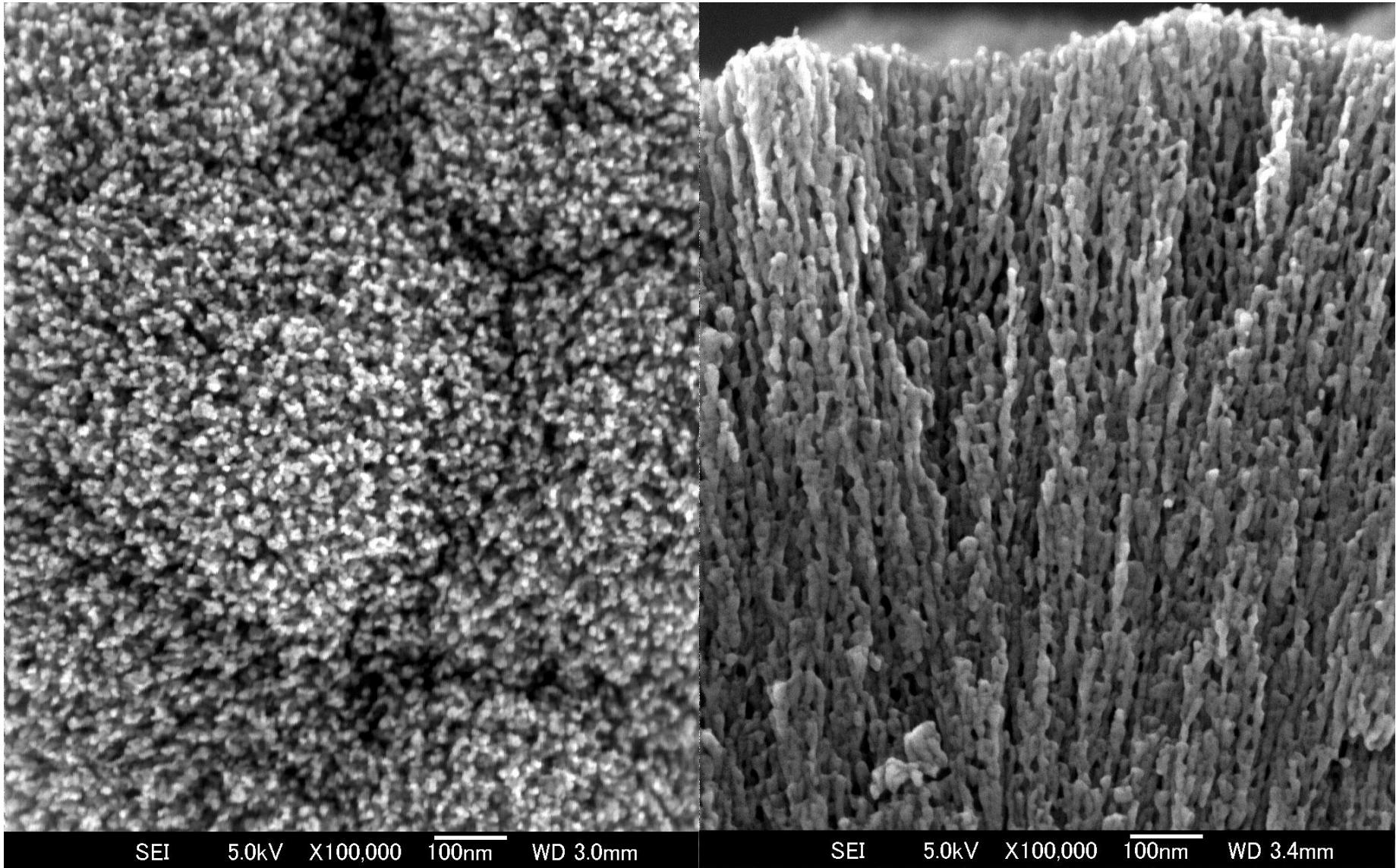
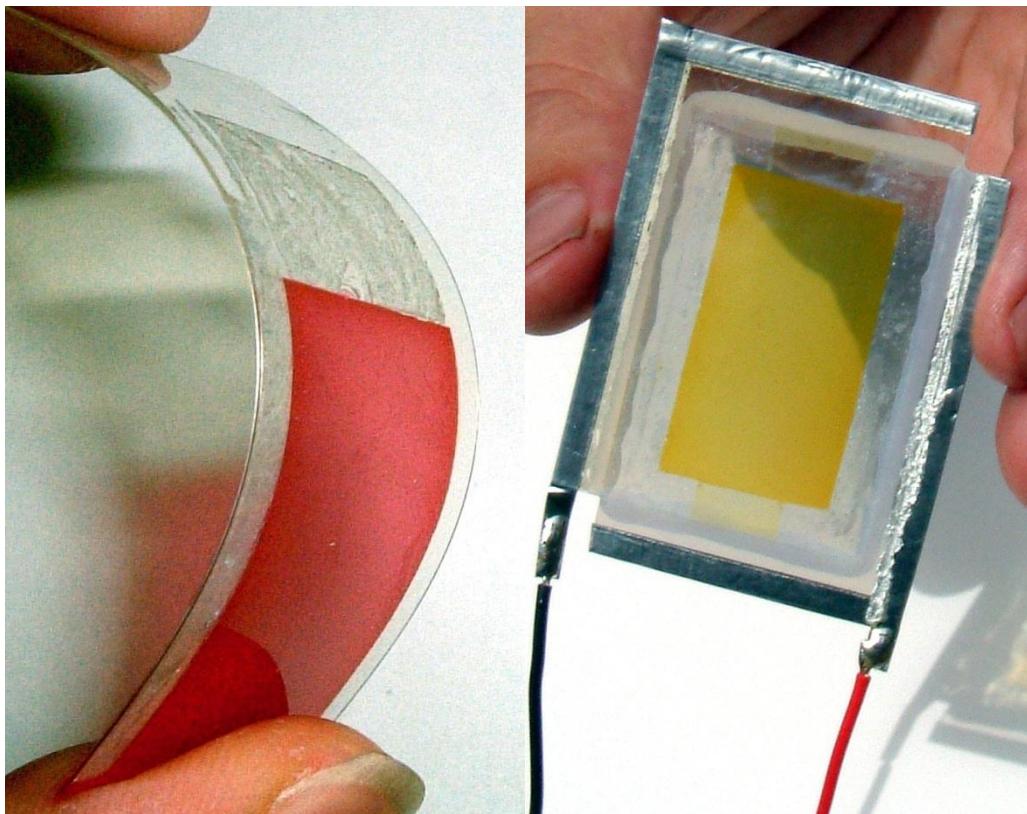
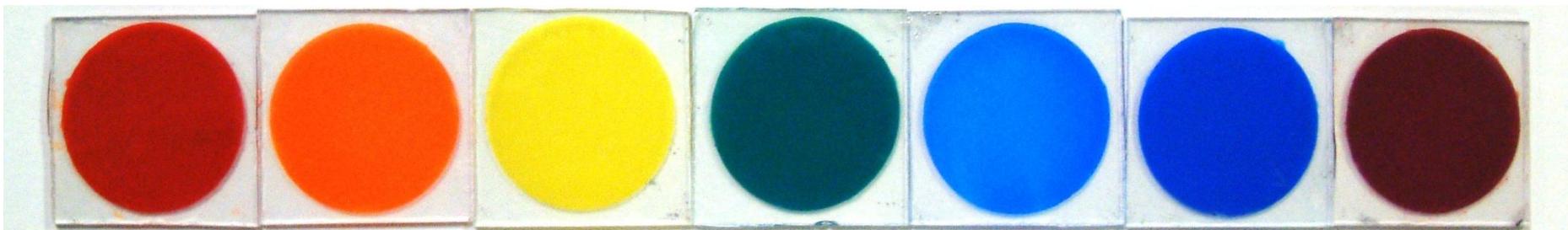


FIGURE 18
Principe de fonctionnement
d'une cellule à colorants.



Source : D. Lincot, T. Pauperté, ZnO nanoporeux préparé par électrolyse



Rendement actuel 5,6 %

T. Yoshida et al.

Et tout cela c'est pour quand?

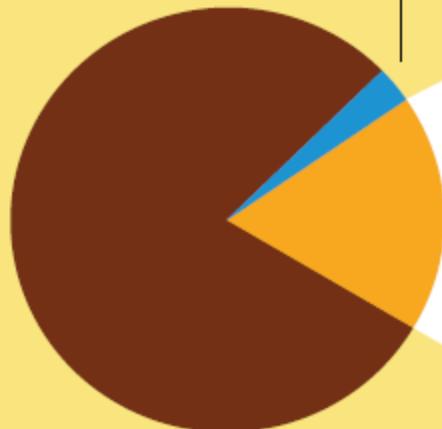


Renewable Energy Share of Global Final Energy Consumption, 2006

Nuclear 3 %

Fossil fuels 79 %

Renewables 18 %



Biofuels 0.3 %

Power generation 0.8 %

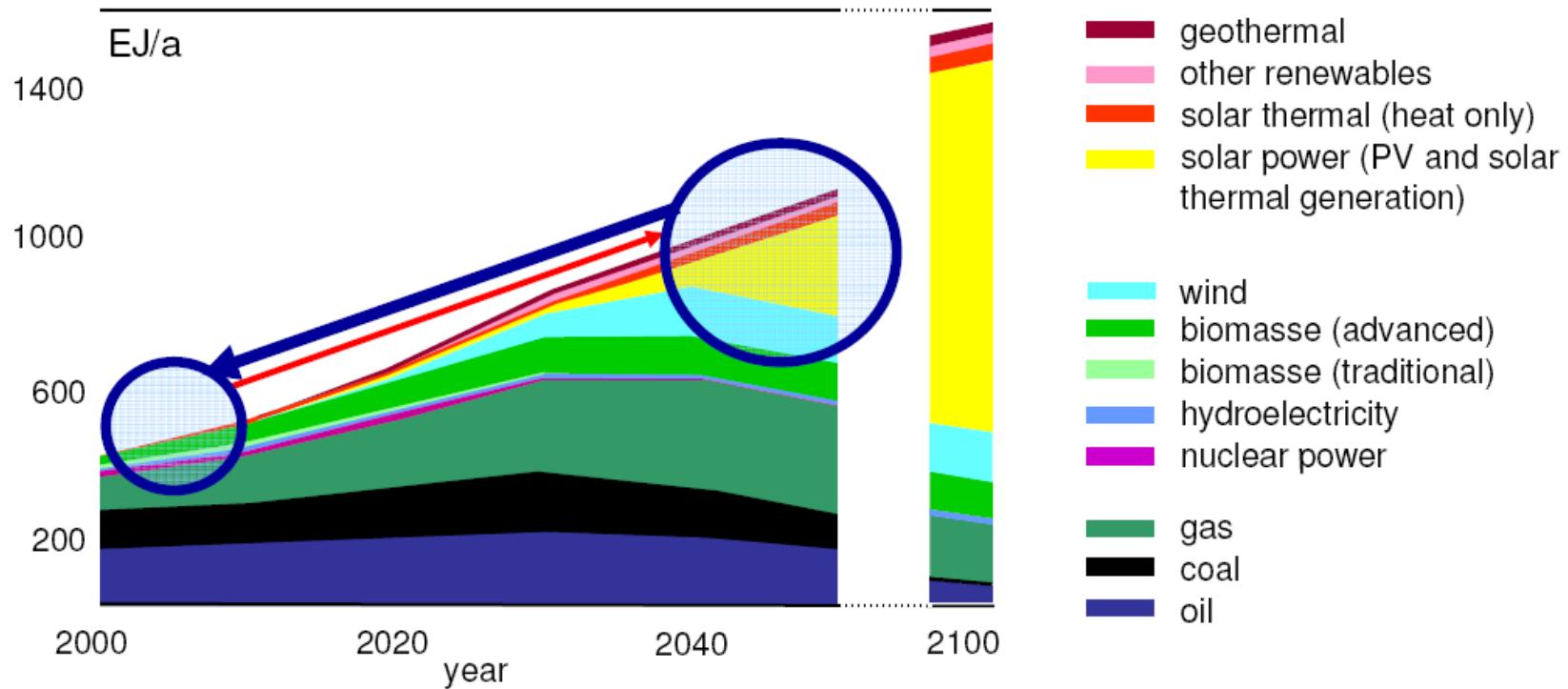
Hot water / heating 1.3 %

Large hydropower 3 %

Traditional biomass 13 %

Source: REN21 (2008): Renewables 2007 Global Status Report.





Source: German Advisory Council on Global Change, 2003, www.wbgu.de

Presented by: Adel El Gammal, EPIA, EUPV TP June 2008

**Present context leads
To an acceleration of Solar energy uptake :
-20% renewable in Europe in 2020
-12% of electricity from photovoltaics**



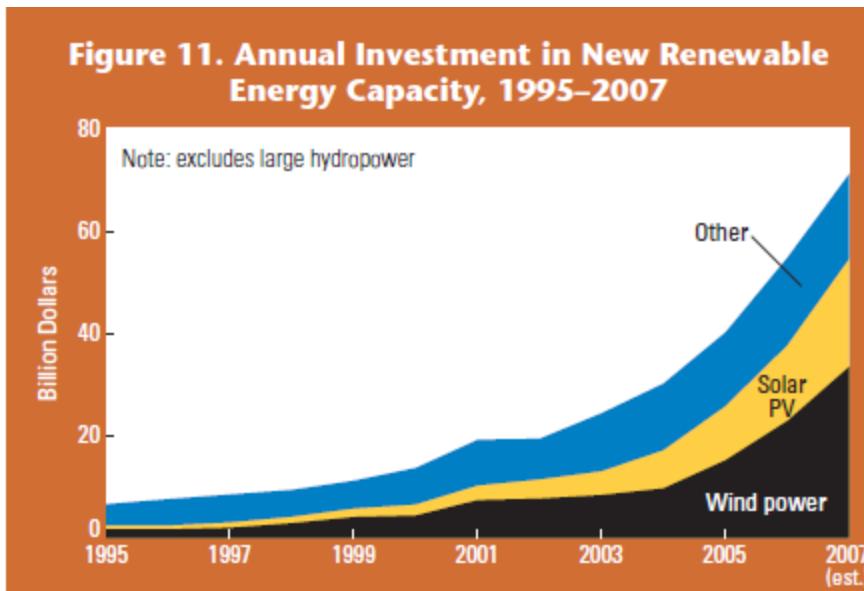
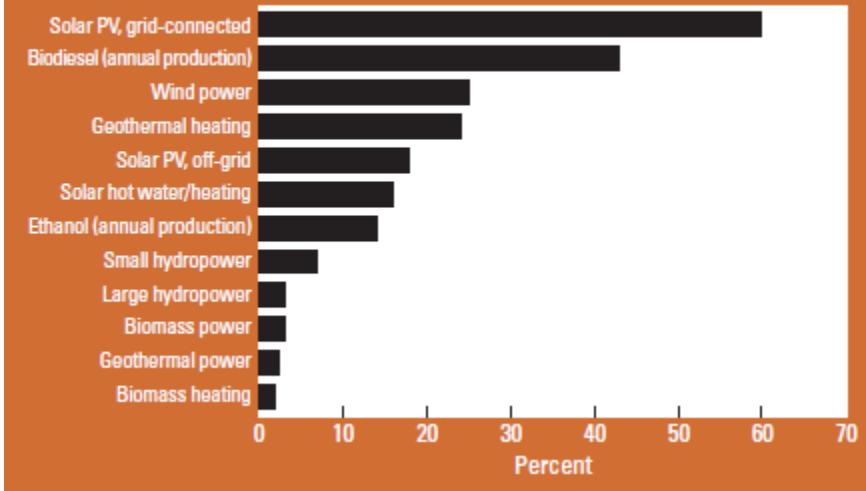
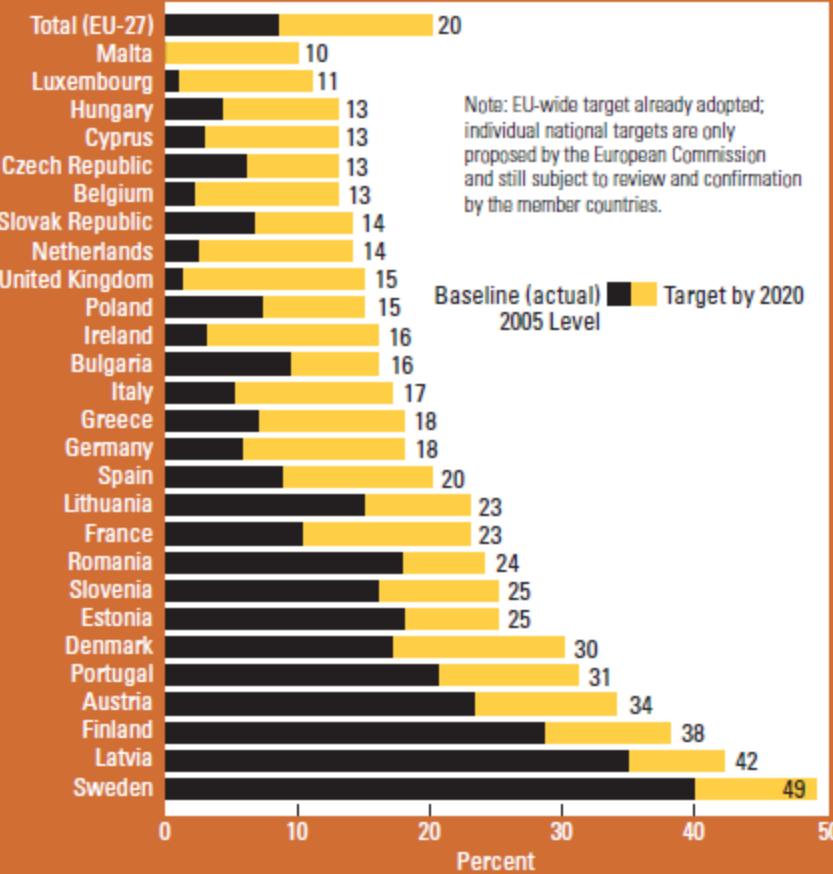


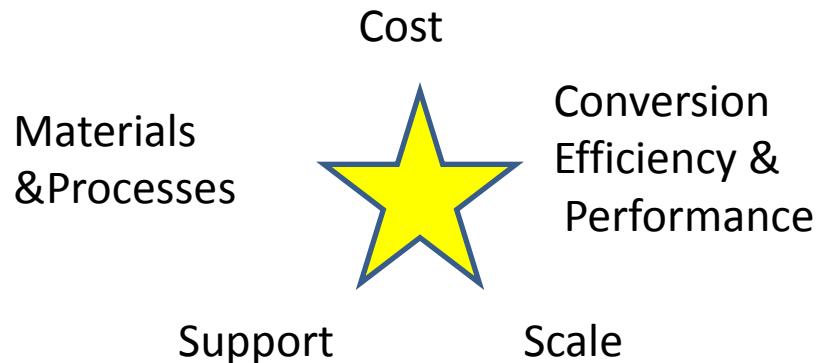
Figure 3. Average Annual Growth Rates of Renewable Energy Capacity, 2002–2006



**Figure 12. EU Renewable Energy Targets—
Share of Final Energy by 2020**



La recherche de la compétitivité économique



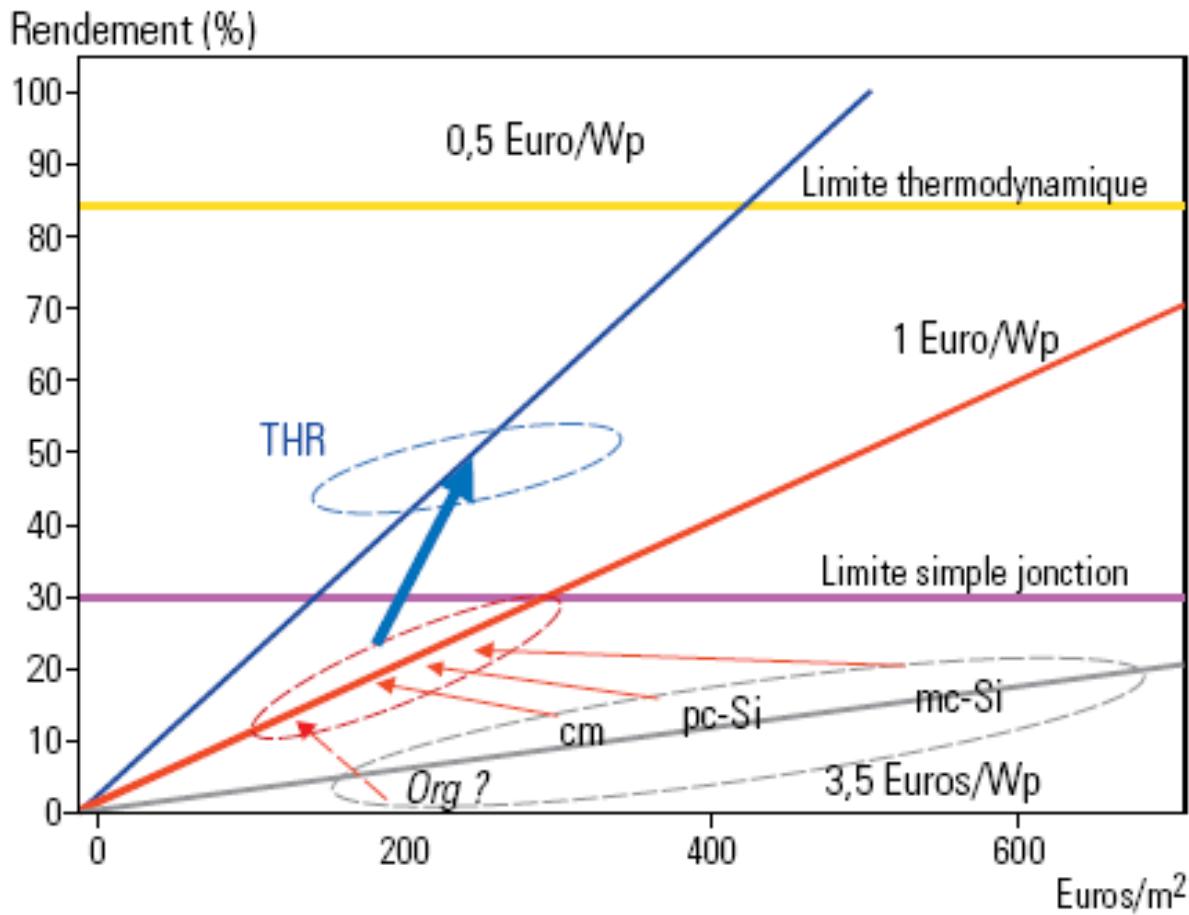
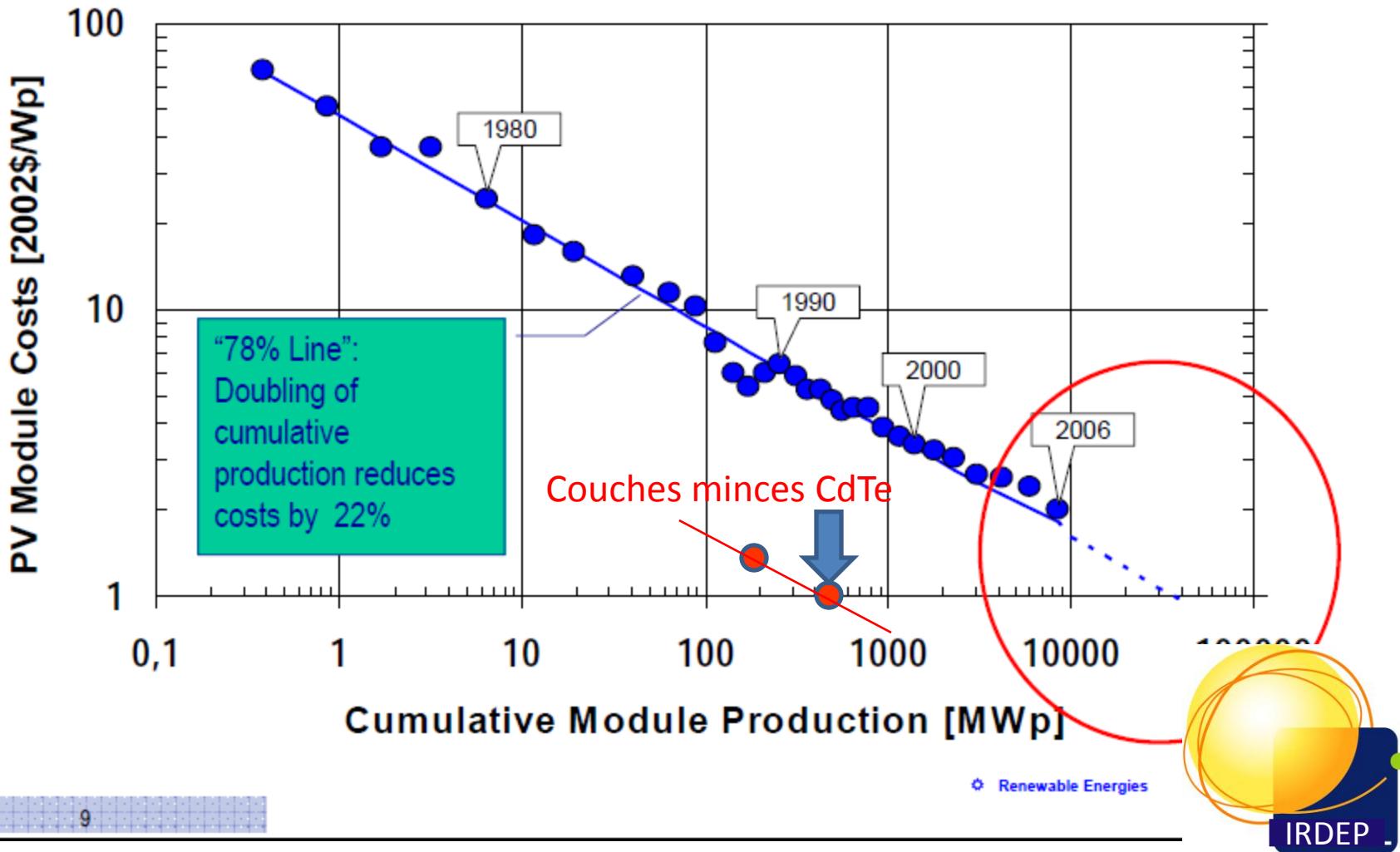


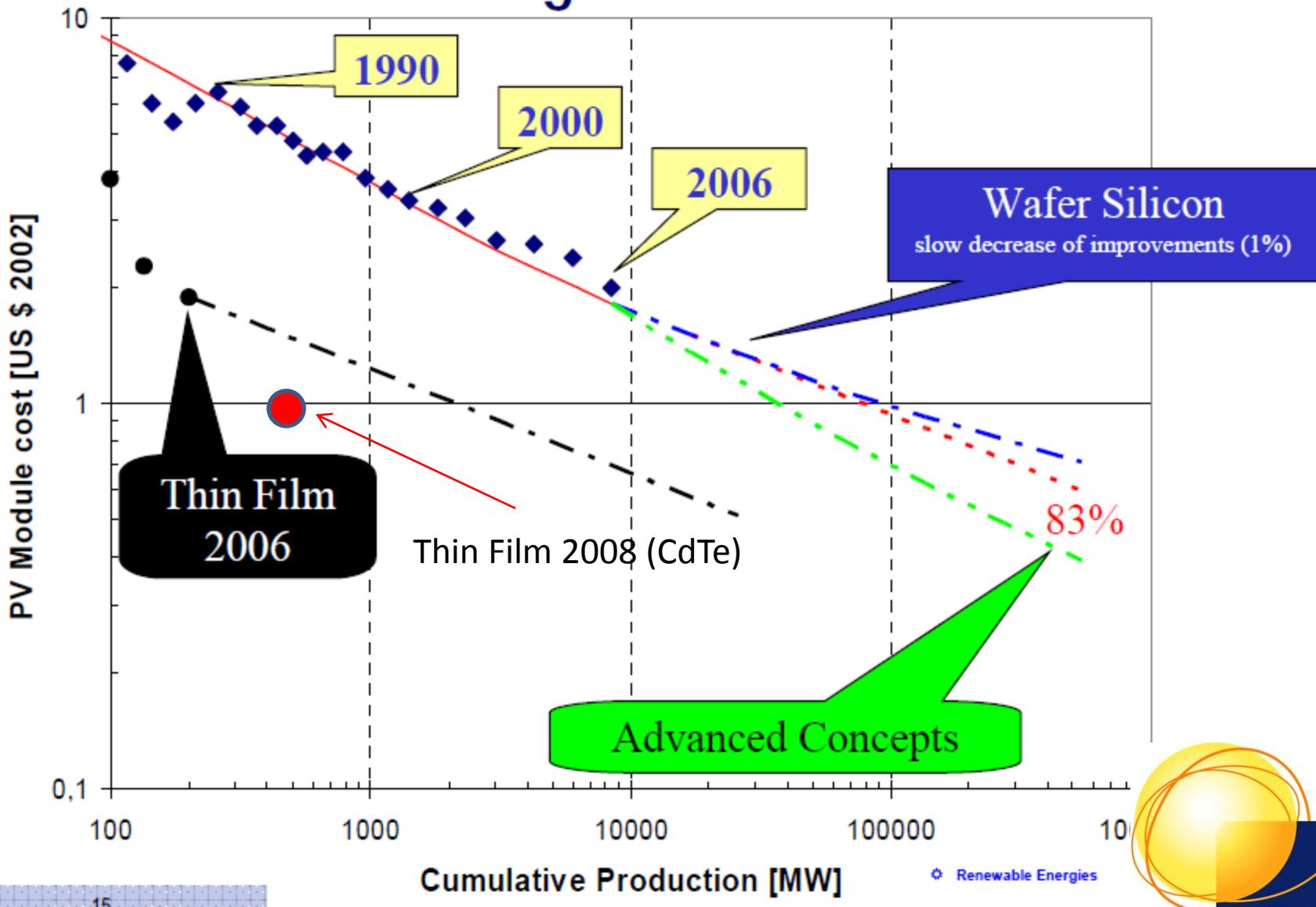
FIGURE 16
Stratégies de réduction des coûts de l'électricité photovoltaïque. Adapté de J.-F. Guillemoles.

PV Technology Learning Curve since '76





Learning Curve Scenarios



Tarif d'achat – Éléments-clés

- ❖ Outil efficace qui s'est déjà révélé porter ses fruits
- ❖ Mécanisme temporaire
- ❖ Pas un fardeau pour les contribuables
- ❖ Moteur pour d'autres réductions de coûts et économies d'échelle
- ❖ Garantie de systèmes PV de qualité supérieure et de bonnes performances
- ❖ Création de conditions sûres pour des investisseurs potentiels

Mesures annexes importantes :

- ❖ Élimination des barrières administratives
- ❖ Accès au réseau garanti

Figure 4.1 : Développement des prix du distributeur et coûts de la production PV

Cout des systèmes complets

Modules

+ systèmes

+ installation

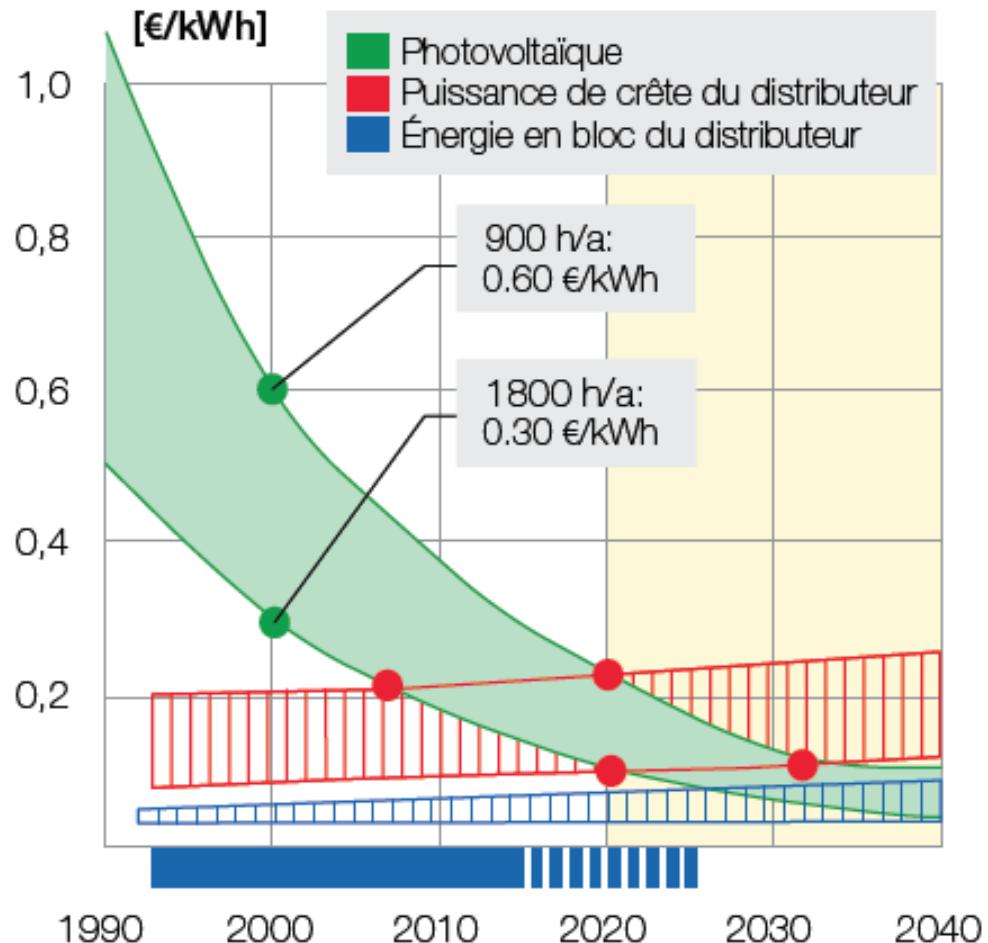
+ entretien

Aujourd'hui :

2,5 Euros/ W

grands systèmes

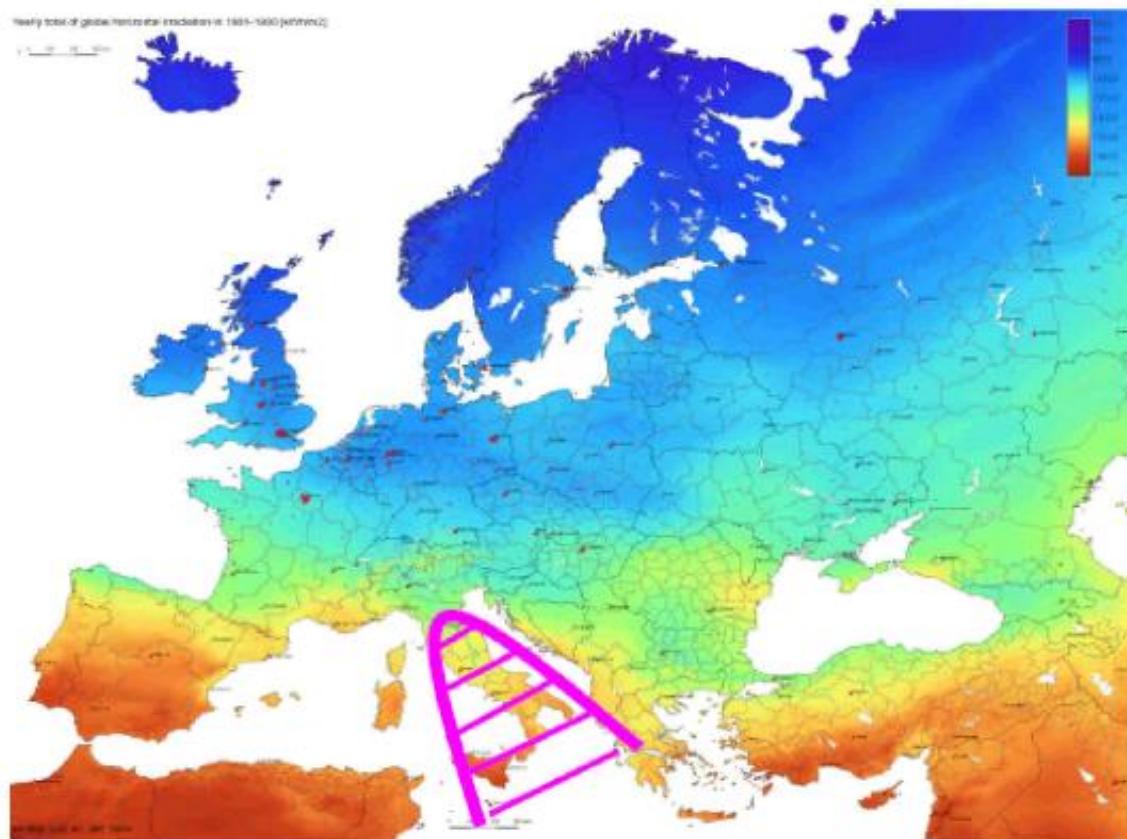
3-3,5 E/W toitures → 2 E/W (2015)



Remarque : la bande bleue indique que des programmes de soutien du marché seront nécessaires jusqu'environ 2020 sur certains marchés.

Grid parity in Europe – 2010

(lines to guide the eye)

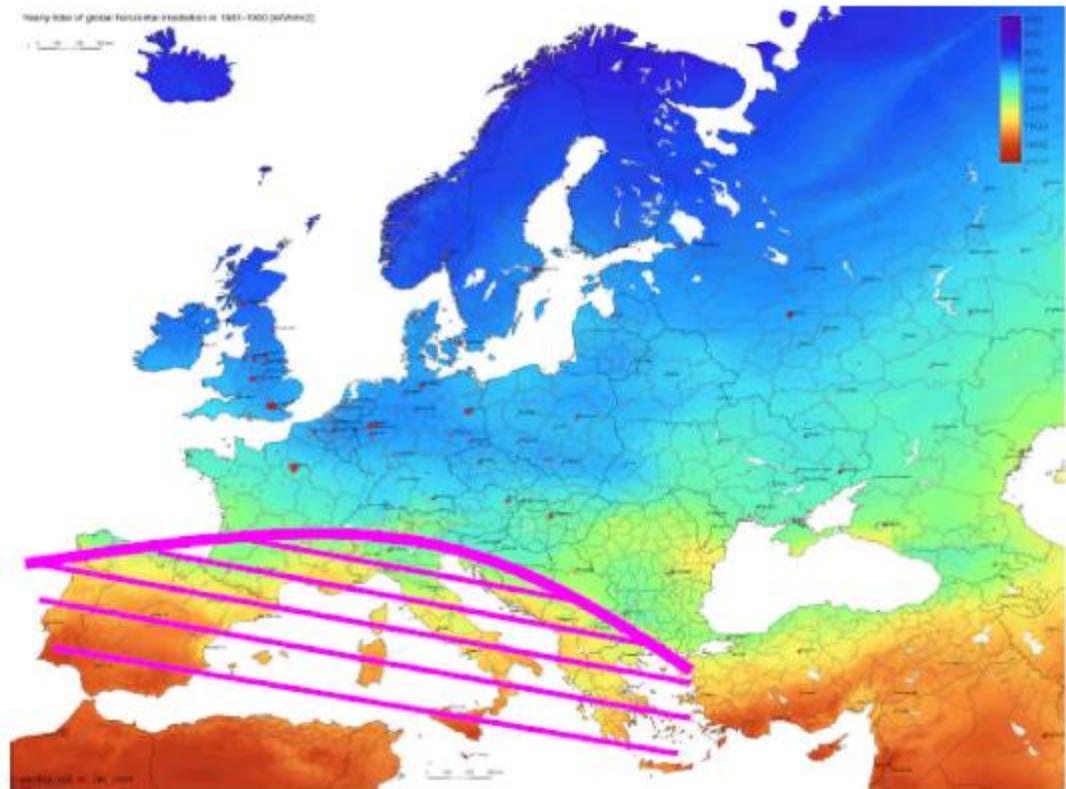


irradiation (kWh/m ² -yr)	PV generation cost (€/kWh)
600	0.50
1000	0.30
1400	0.21
1800	0.17

Grid parity in Europe – 2015

(lines to guide the eye)

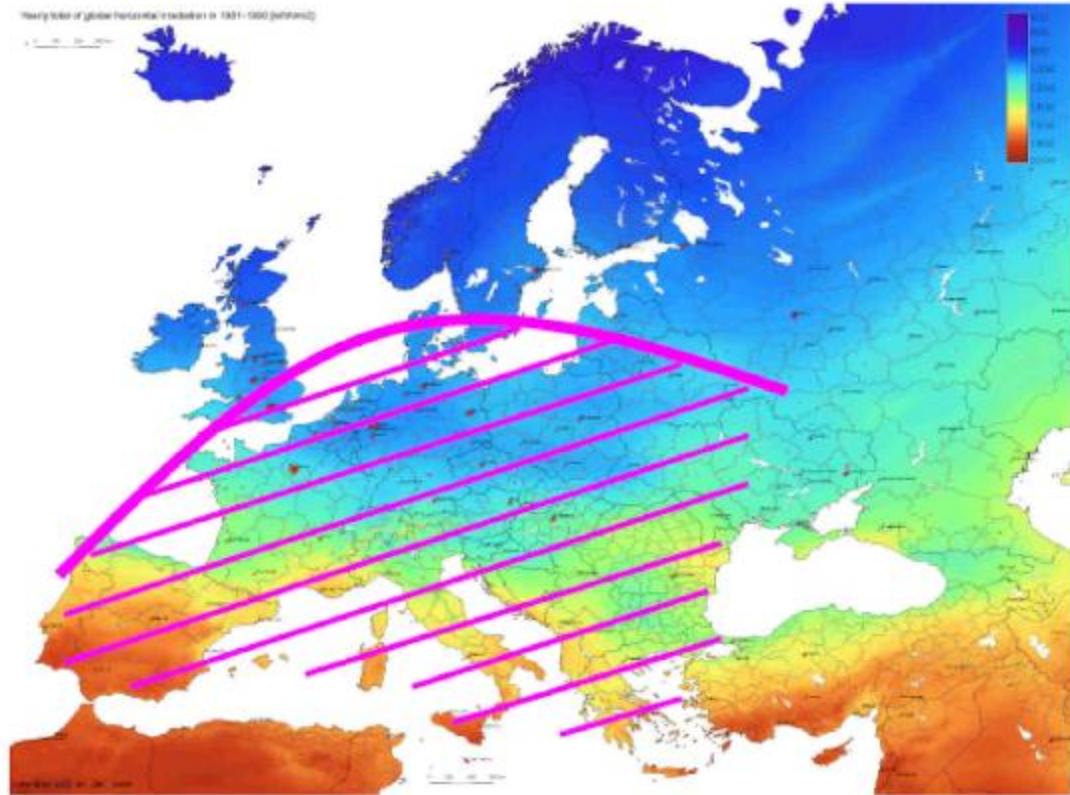
Mean level of global horizontal irradiation in 1981–1990 (W/m²)



irradiation (kWh/m ² .yr)	PV generation cost (€/kWh)
600	0.42
1000	0.25
1400	0.18
1800	0.14

Grid parity in Europe – 2020

(lines to guide the eye)



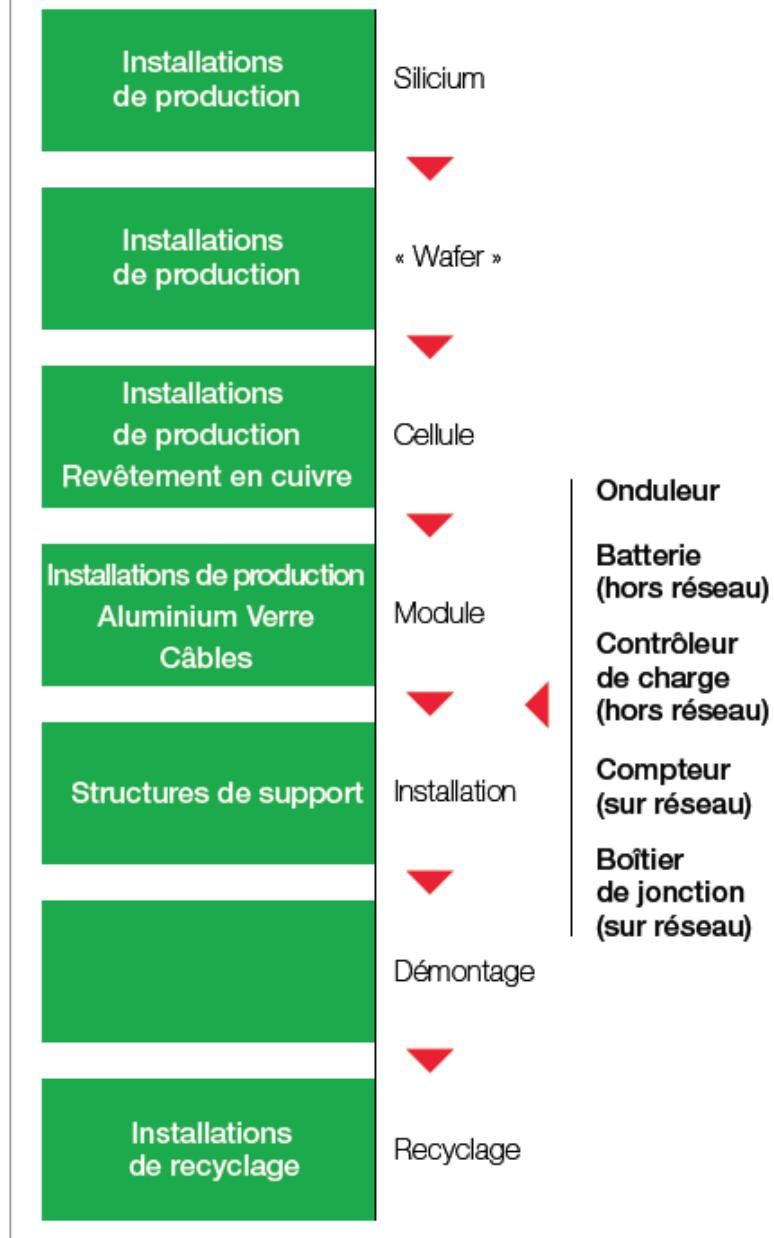
irradiation (kWh/m ² .yr)	PV generation cost (€/kWh)
600	0.33
1000	0.20
1400	0.14
1800	0.11

PV Electricity will be competitive within the next year

Et les autres questions? « Analyse du cycle de vie »



Figure 1.3 : Cycle de vie d'un système PV (c-Si)



COMPARED ASSESSMENT OF SELECTED ENVIRONMENTAL INDICATORS OF PHOTOVOLTAIC ELECTRICITY IN OECD CITIES

IEA PVPS Task 10, Activity 4.4

Report IEA-PVPS T10-01:2006

This technical report has been prepared under the supervision of
PVPS Task 10 by:

Bruno Gaiddon and Marc Jedliczka, Hespul, Villeurbanne, France;
in co-operation with Task 10 experts from:
United States, Portugal and Denmark

The compilation of this report has been supported by the French Agency for Environment and Energy
Management, ADEME

L'énergie « grise » et le temps de retour énergétique



Table 1 – Energy input of current technology grid connected PV system expressed in primary energy

	Primary energy [MJ/kWp]
Laminate	25 606
Frame	1 061
Balance of system	2 660
Total system	29 327

Table 2 – Energy input of current technology grid connected PV system expressed in final electrical energy

	Electrical energy [kWh/kWp]
Laminate	2 205
Frame	91
Balance of system	229
Total system	2 525

The source of data [7] uses a grid efficiency value of 31%, which is the commonly agreed value for Western Europe Mainland medium voltage grid (the so-called “UCTE Region”). It includes:

Table 5 – Energy Payback Time of Urban Scale PV systems

	Minimum value [Years]	Maximum value [Years]
Roof-top mounted PV system	1,6	3,3
PV facade	2,7	4,7

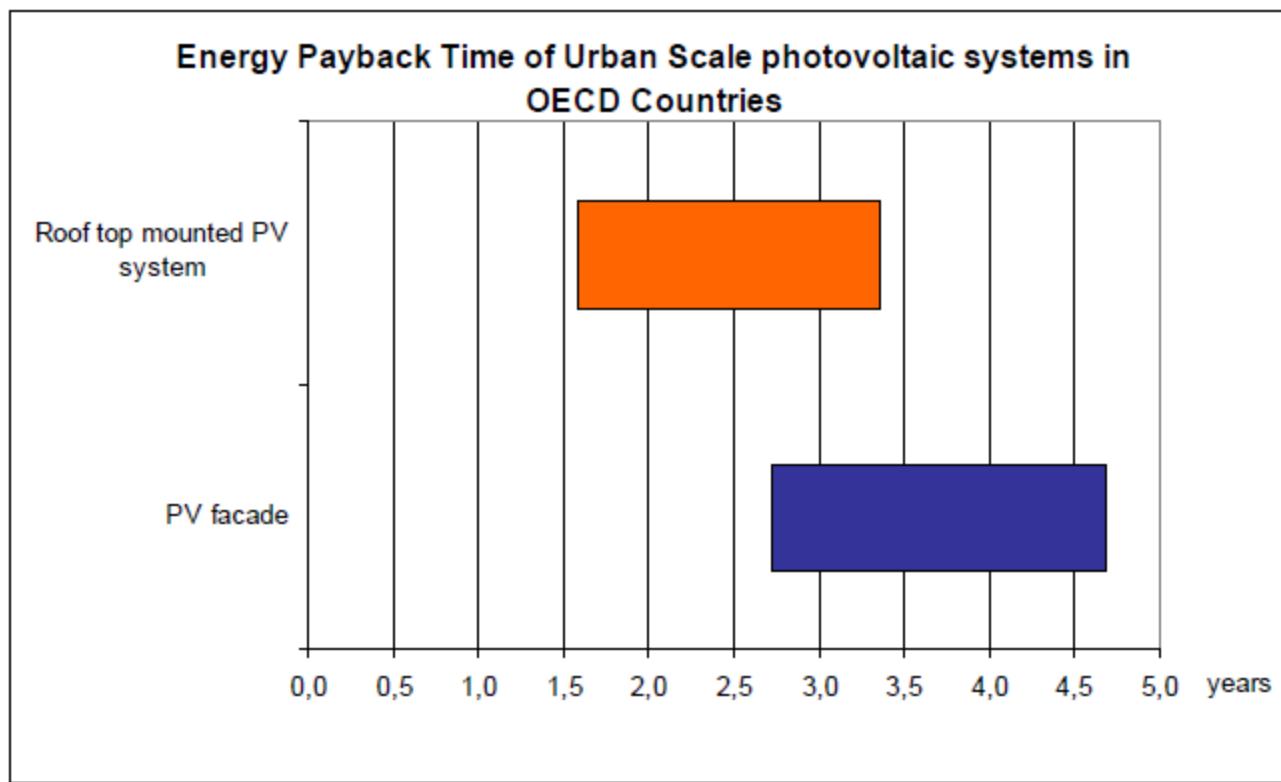


Figure 3 : EPBT of Urban Scale PV systems

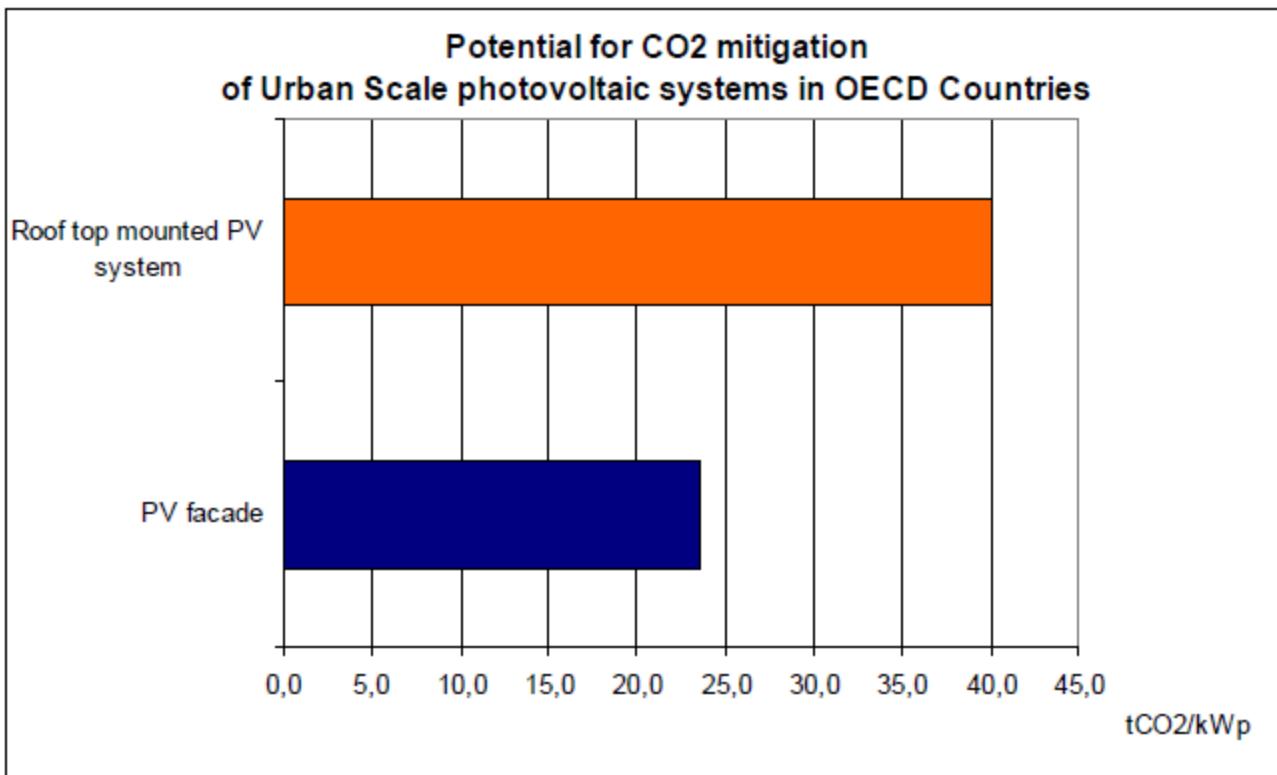


Figure 5 : potential for CO₂ mitigation of Urban Scale PV systems

Table 8 : results for the considered city

Lyon	Global horizontal irradiation	
	Roof-top	Façade
Annual output [kWh/kWp]	984	632
Energy Pay-Back Time [years]	2,6	4,0
Energy Return Factor [number of times]	10,7	6,5
Potential for CO ₂ mitigation [tCO ₂ /kWp]	2,4	1,5

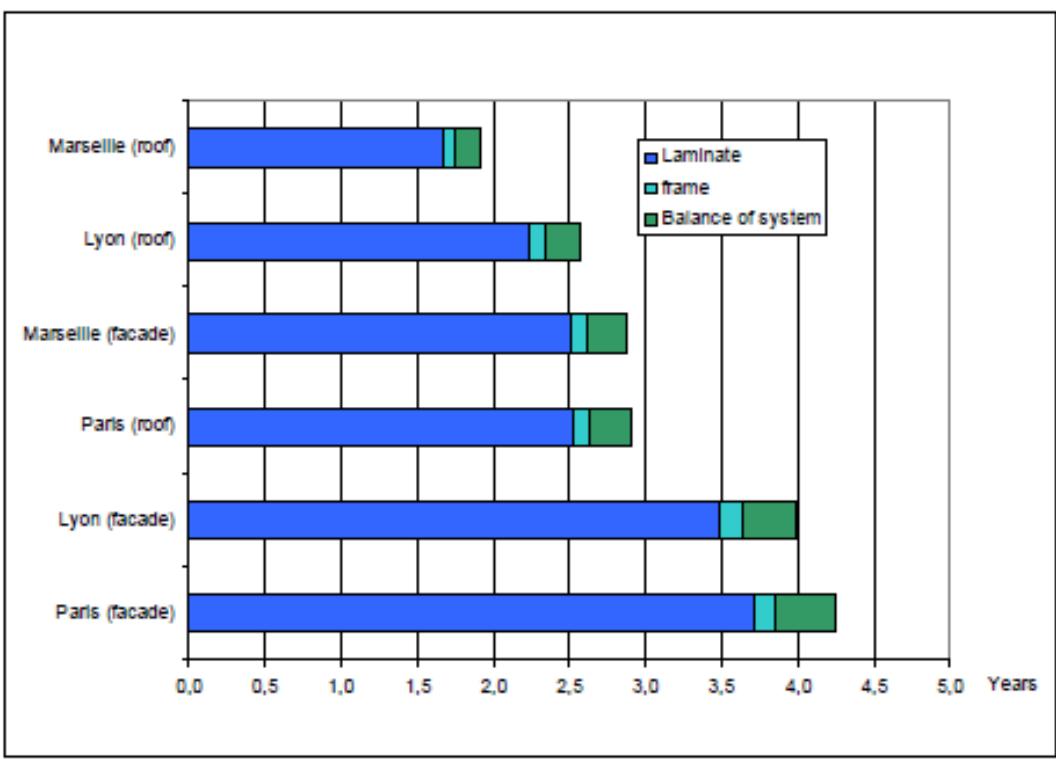


Figure 7 : Energy Payback time

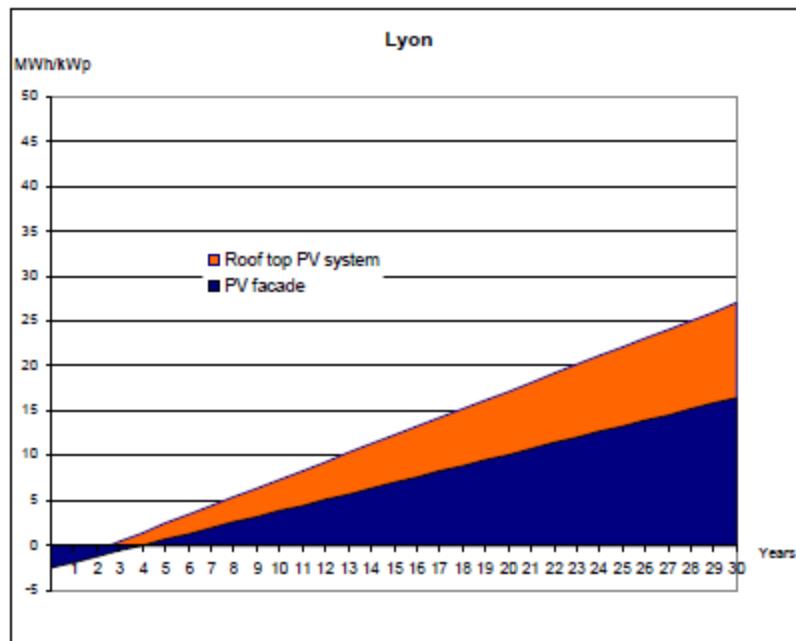


Figure 8 : Energy Payback time

LIFE CYCLE ASSESSMENT OF PHOTOVOLTAICS: UPDATE WITHIN ECOINVENT DATA V2.0

N. Jungbluth, R. Frischknecht, M. Tuchschnitt
ESU-services Ltd.

Kanzleistrasse 4, CH – 8610 Uster, Switzerland, Tel. +41 44 940 6191, Fax. +41 44 940 6194, www.esu-services.ch

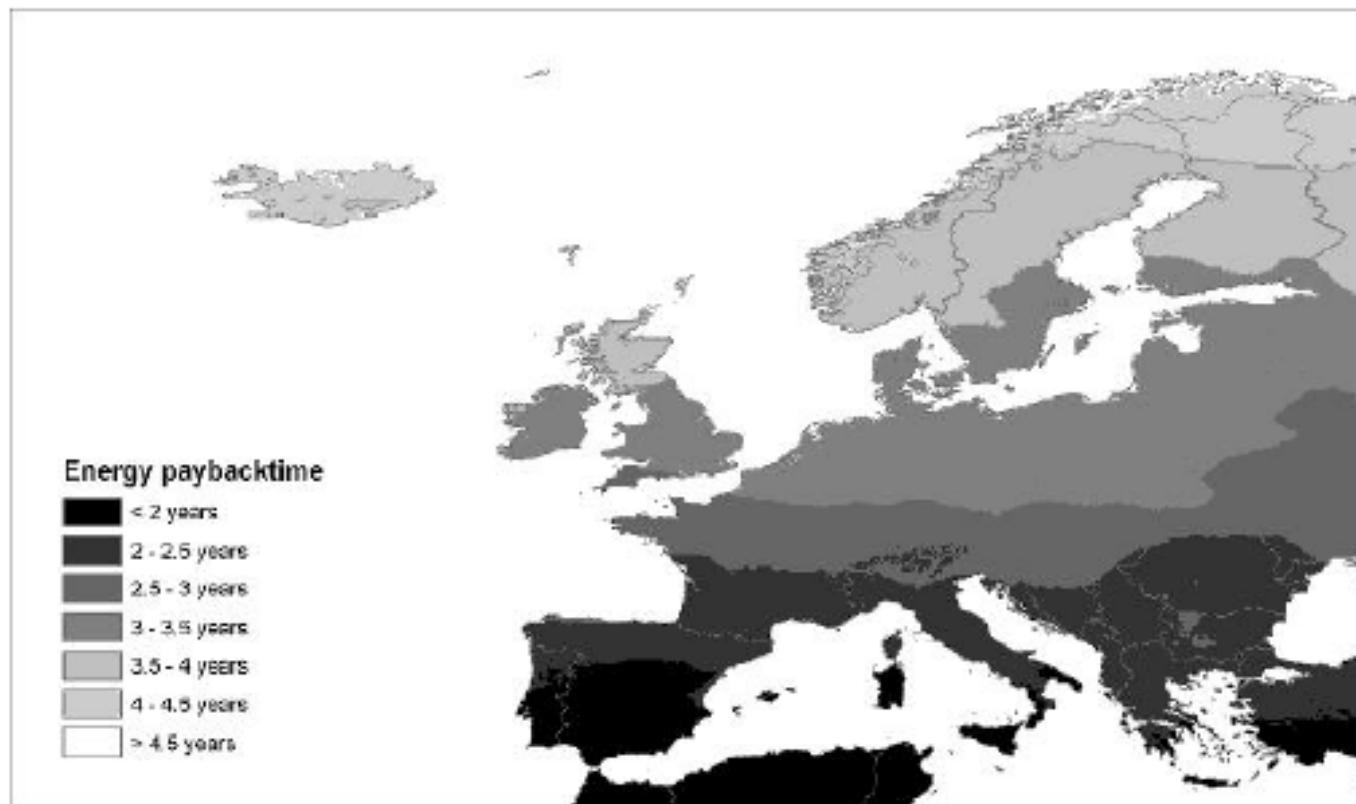


Figure 4: Energy pay back time of 3 kWp slanted-roof multicrystalline panels operated in Europe in relation to the UCTE electricity mix (own calculation with [40])

Broader Perspectives

Energy Payback Time of Grid Connected PV Systems: Comparison Between Tracking and Fixed Systems

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²Solar Energy Institute, UPM, Ciudad Universitaria, s/n 28040 Madrid, Spain

³Electrical and Computer Engineering Department/UNED, Juan del Rosal, 12 Ciudad Universitaria, 28040 Madrid, Spain

⁴Zilis Ltd., 308 Des Voeux Road, Hong Kong Central, China

Table II. Technical characteristics of an average module manufactured by Isofoton. All the amounts are referred to a nominal PV power of 1 kWp

Parameter	Amount
Efficiency	12.4%
Weight	110 kg
Frame weight	23 kg
Proportion of recycled aluminium	60%
Glass	69.1 kg
EVA	7.9 kg
Tedlar	1.9 kg
Cell	7.36 m ²
Required energy	39 840 MJ

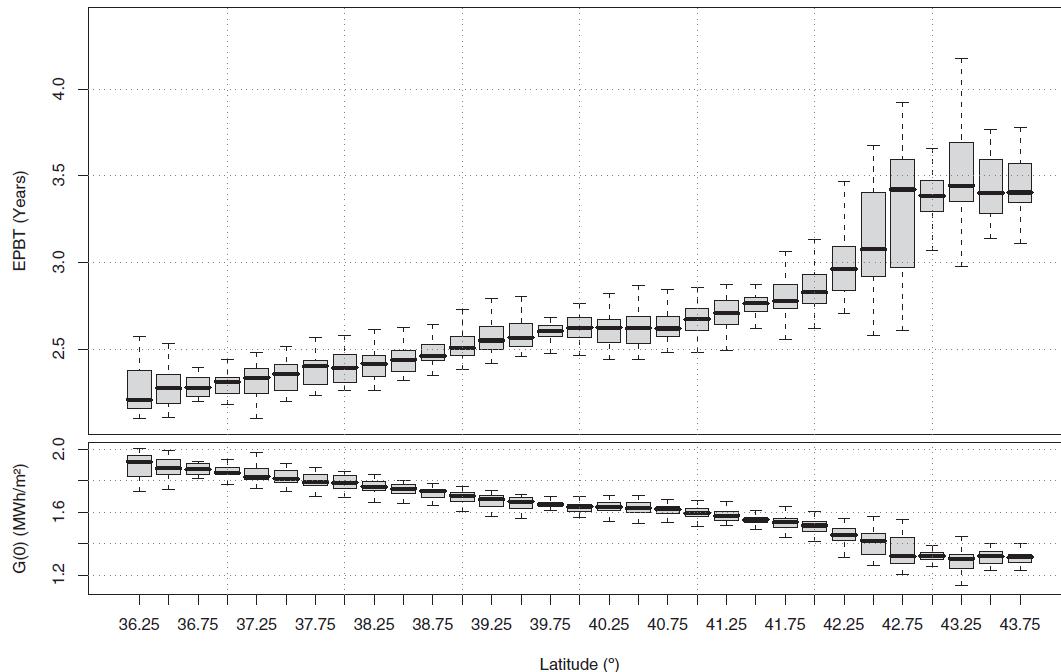
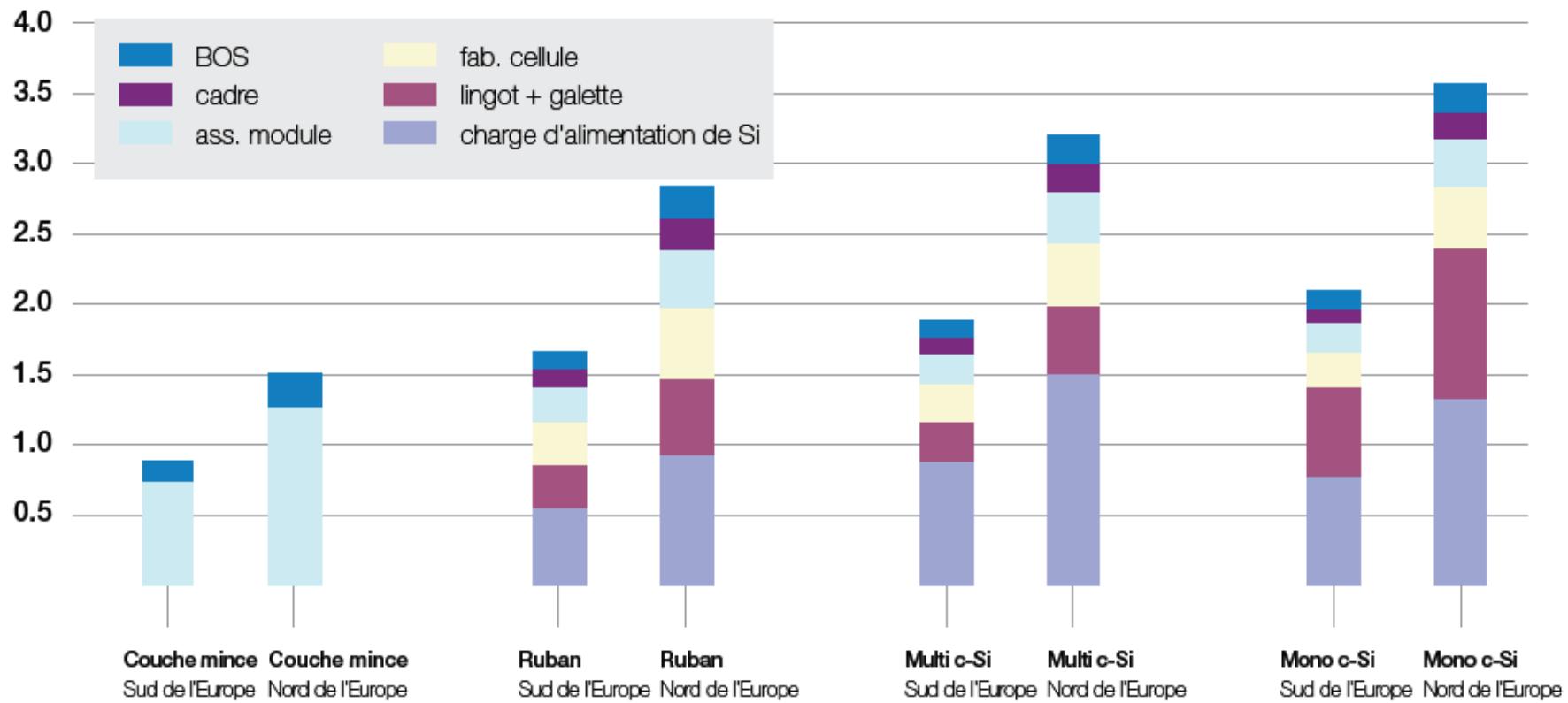


Figure 2. EPBT of a GCPVS with double axis tracking calculated over the geographical area comprised between -10° to 10° of longitude, and 30° to 45° of latitude. The bottom frame of this figure shows the yearly values of horizontal global irradiation as a reference

Figure 5.1 : Retour énergétique de la gamme de systèmes PV



Source: Alsema, De Wild, Fthenakis, 21st European Photovoltaic Energy Conference, Dresden 2006

Les émissions?



Emissions from Photovoltaic Life Cycles

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HYUNG CHUL KIM,[†] AND ERIK ALSEMA^{*}

PV Environmental Research Center, Brookhaven National Laboratory, Upton, New York, Center for Life Cycle Analysis, Columbia University, New York, New York, and Copernicus Institute of Sustainable Development, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands

Received July 17, 2007. Revised manuscript received December 19, 2007. Accepted January 4, 2008.

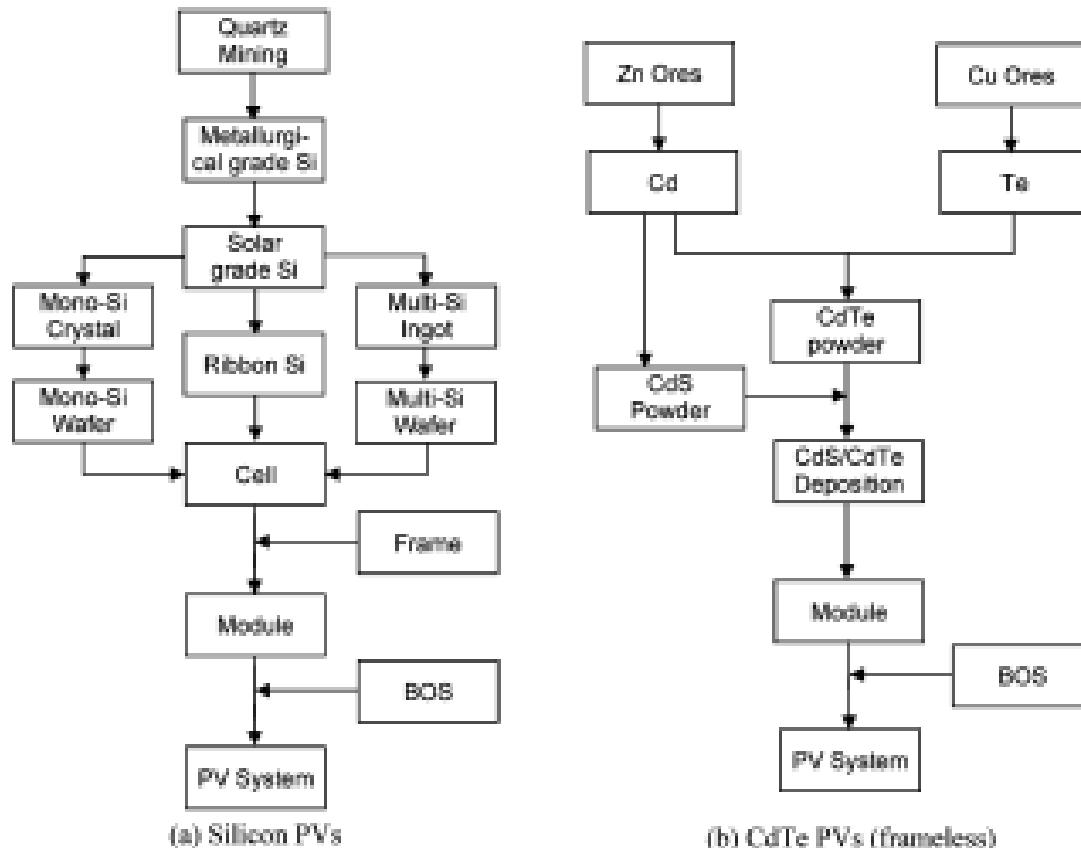


FIGURE 1. Simplified process-flow diagrams from mining to system manufacturing stages, namely cradle-to-gate for (a) mono-, ribbon-, and multi-Si PVs, and (b) thinfilm CdTe PVs. Detailed descriptions of the life cycles are available elsewhere (10, 12, 13).

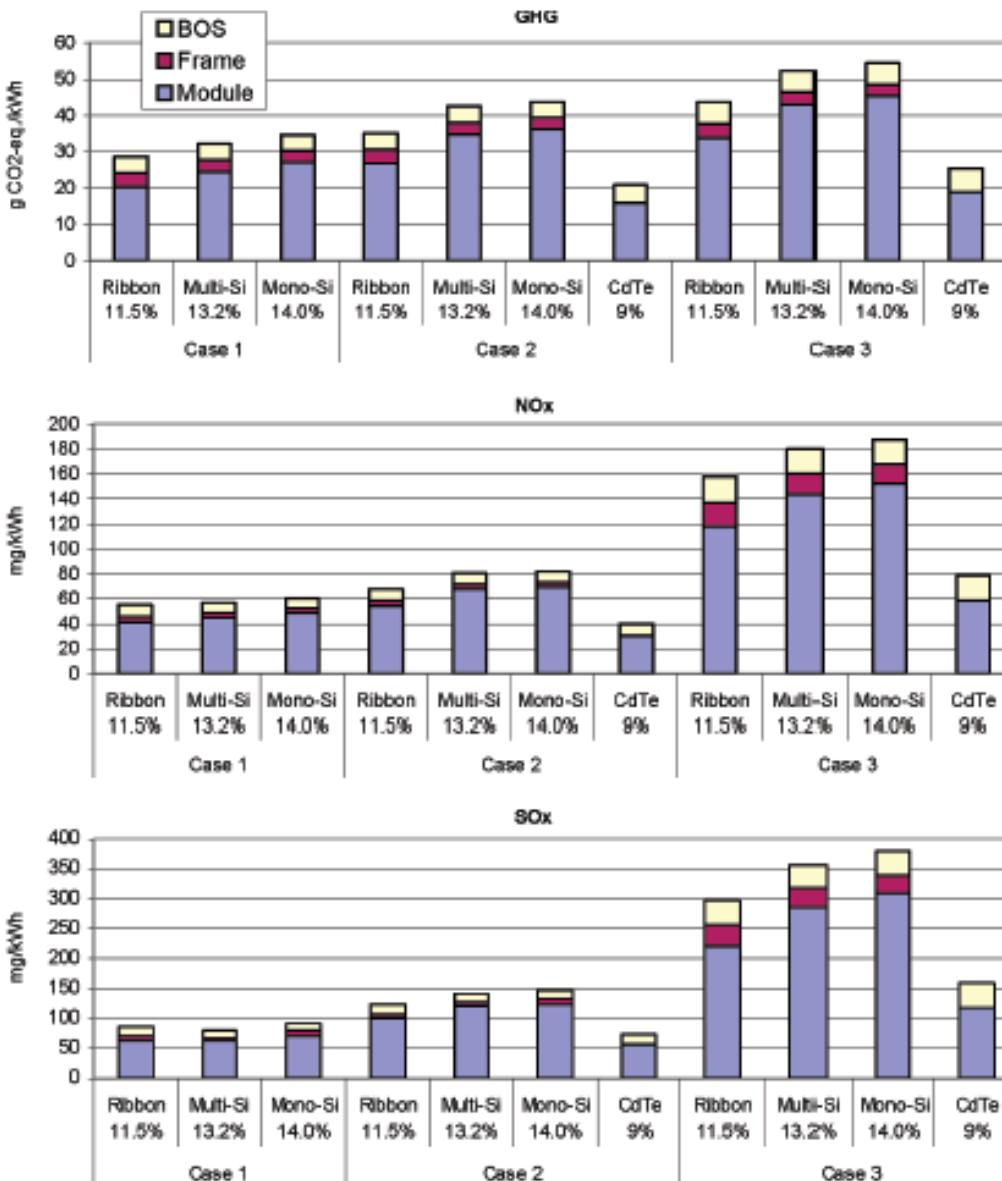


FIGURE 2. Life-cycle emissions from silicon and CdTe PV modules. BOS is the Balance of System (i.e., module supports, cabling, and power conditioning). Conditions: ground-mounted systems, Southern European insolation, 1700 kWh/m²/yr, performance ratio of 0.8, and lifetime of 30 years. Case 1: current electricity mixture in Si production—CrystalClear project and Ecoinvent database. Case 2: Union of the Co-ordination of Transmission of Electricity (UCTE) grid mixture and Ecoinvent database. Case 3: U.S. grid mixture and Franklin database.

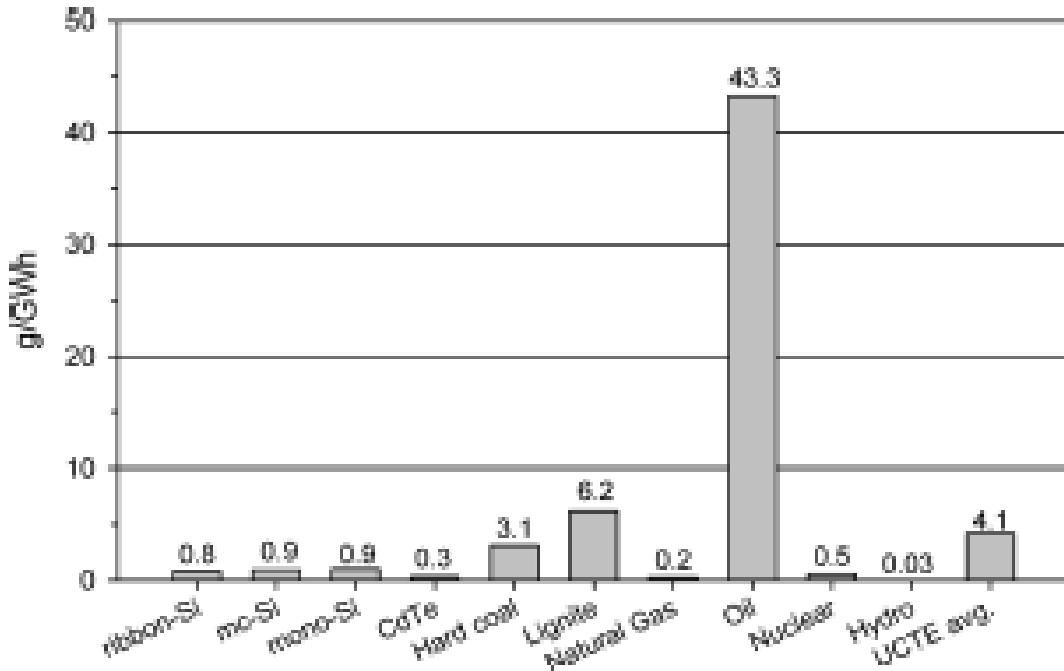


FIGURE 3. Life-cycle atmospheric Cd emissions for PV systems from electricity and fuel consumption, normalized for a Southern Europe average insolation of 1700 kWh/m²/yr, performance ratio of 0.8, and lifetime of 30 yrs. Ground-mounted BOS (18) is assumed for all PV systems; comparisons with other electricity generation options.

Presented at 13th CIRP Intern. Conf. on Life Cycle Engineering, Leuven, 31 May- 2 June 2006

Environmental Impacts of Crystalline Silicon Photovoltaic Module Production

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¹Copernicus Institute of Sustainable Development and Innovation,
Utrecht University, The Netherlands

²Energy research Centre of the Netherlands (ECN), Petten, The Netherlands

System boundary LCA study

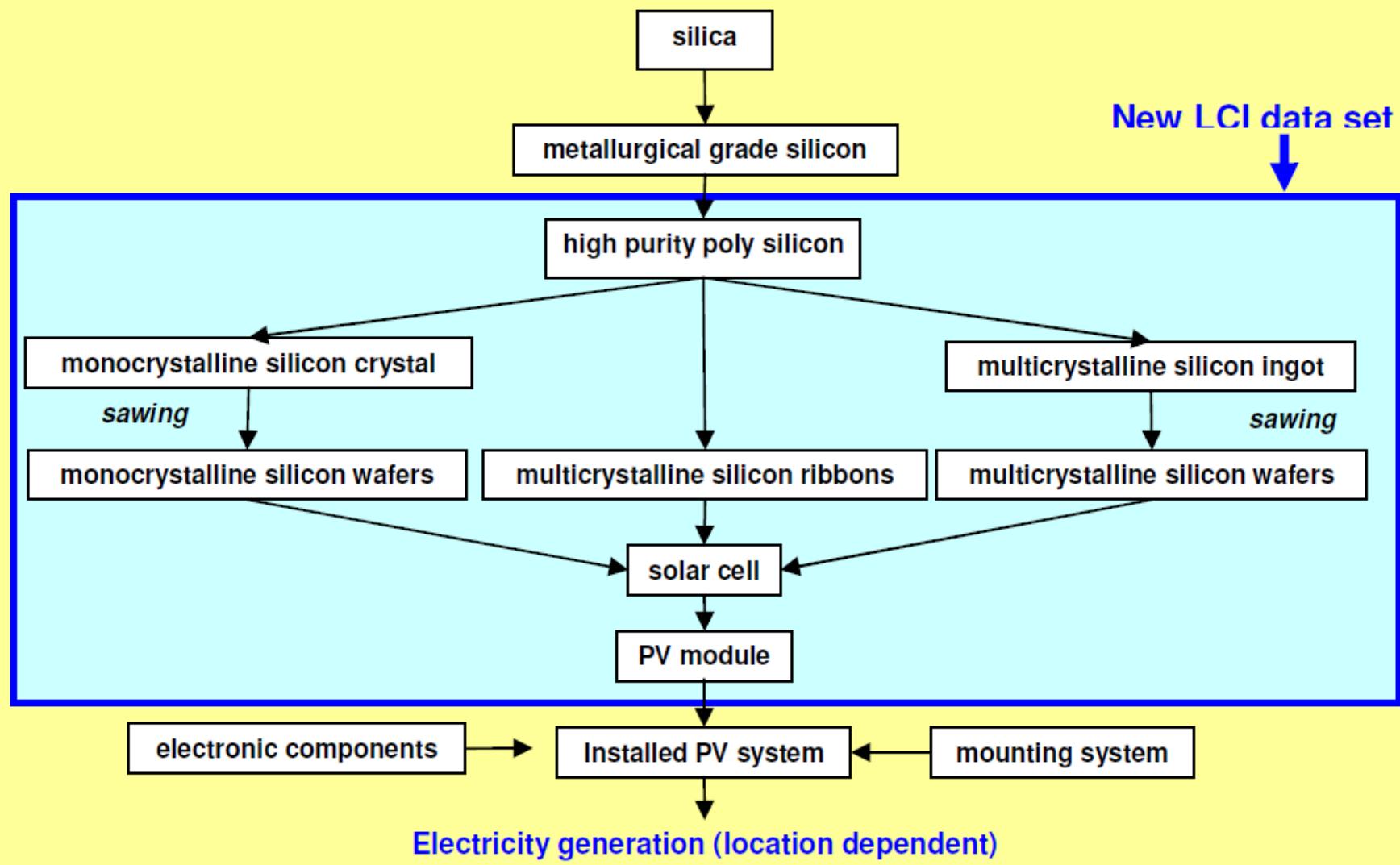


Figure 1: System boundary for LCA study and for new LCI data collection

FLUORINATED GREENHOUSE GASES IN PHOTOVOLTAIC MODULE MANUFACTURING: POTENTIAL EMISSIONS AND ABATEMENT STRATEGIES

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Energy research Centre of the Netherlands ECN, Unit Solar Energy, P.O. Box 1, 1755 ZG Petten, the Netherlands

E.A. Alsema, e.a.alsema@chem.uu.nl, Phone +31 30 2537618,

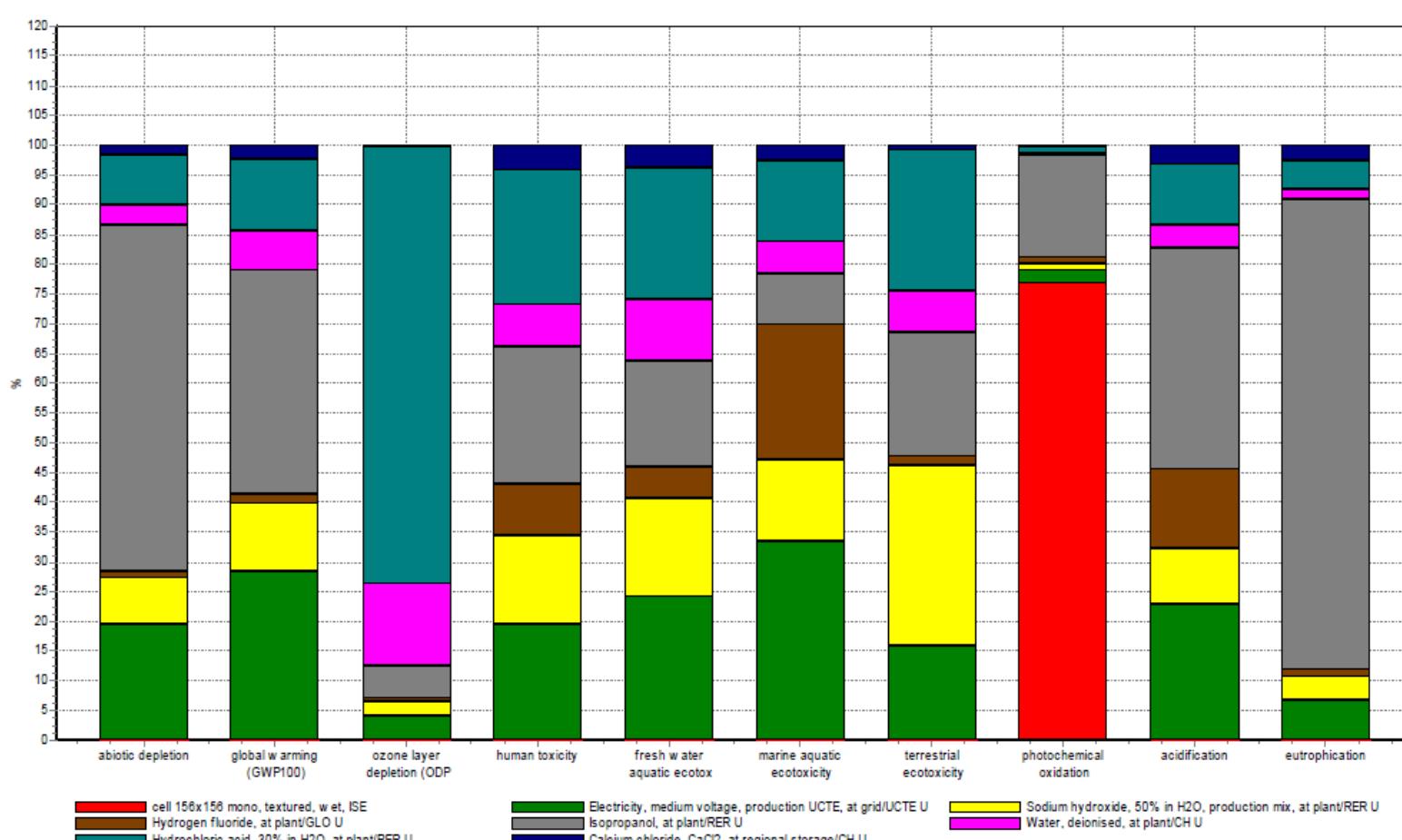
Copernicus Institute, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands

V.M. Fthenakis, vmf@bnl.gov, Phone +1 631 344 2830,

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Le recyclage



RECYCLING OF SILICON, ENVIRONMENTAL FOOTPRINTS AND ECONOMICS

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Alfred-Lange-Straße 18, D-09599 Freiberg, Germany
email: karsten.wambach@deutschesolar.de

Table 2: Cumulative Energy Demand per ton recovered silicon (non-renewable energy: fossil and nuclear energy resources)

	CED (MJ-Eq. per ton)
Pot scrap	7,957
Recycled mc tops or bottoms	28,676
Recycled mc sides	29,489
Recycled wafer breakage	1,966
Recycled wafer breakage (partly processed)	2,968
Recycled cell breakage	73,527
Remelted silicon	245,536
Silicon, solar grade	415,023

L'avenir?





Scénario accéléré pour l'Europe (2009) :
12% de l'électricité d'origine photovoltaïque

Figure 3.2 : Capacité installée annuelle du PV mondiale jusqu'en 2030

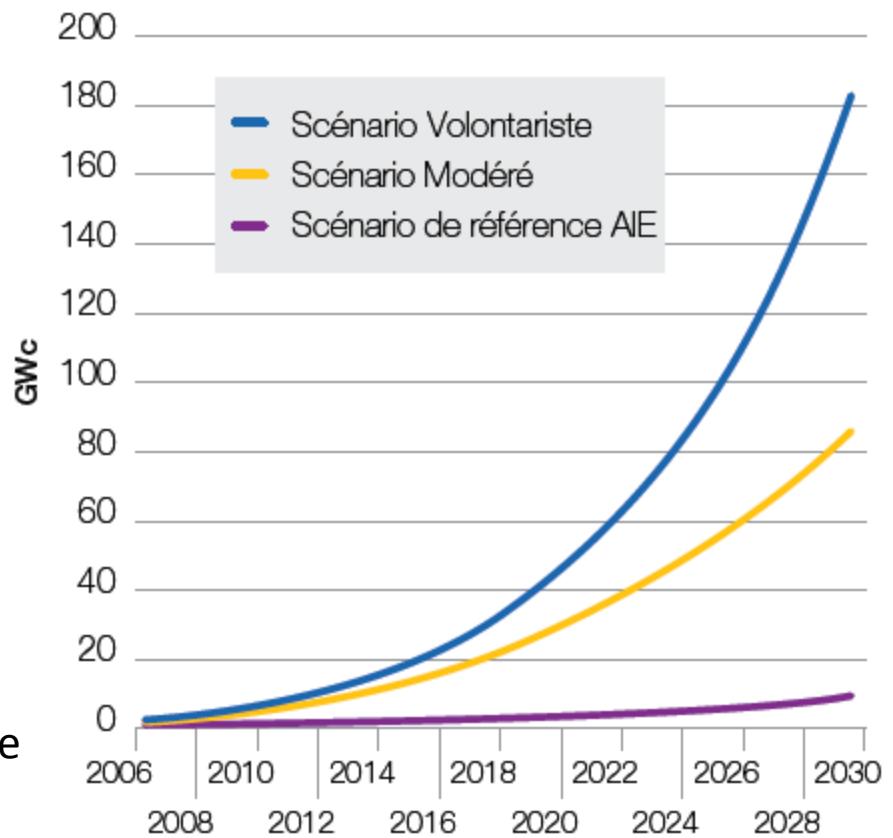


Tableau 3.1 : Résultats du scénario Solar Generation pour le marché PV mondial jusqu'en 2030

	Situation actuelle	Scénarios			
		2006	2010	2020	2030
Scénario Volontariste					
Installations annuelles en GW		1,5	5,6	44	179
Capacité totale en GW		6,6	21,9	241	1,272
Production d'électricité en TWh		8	25	320	1,802
Contribution du PV à la consommation d'électricité – Scénario de référence (AIE)		0,05 %	0,14 %	1,83 %	6,41 %
Contribution du PV à la consommation d'électricité – Scénario Alternatif		0,05 %	0,18 %	1,93 %	9,39 %
Personnes connectées au réseau en millions		5	15	157	776
Personnes connectées hors réseau en millions		10	61	966	2,894
Emplois en milliers		74	271	1,840	6,329
Valeur du marché en milliards €		9	25	113	318
Économies de CO ₂ annuelles en millions de tonnes		5	15	192	1,081
Économies de CO ₂ totales en millions de tonnes		20	61	898	6,671

Tableau 3.2 : Scénario Solar Generation : Développement du marché PV (capacité installée annuelle) jusqu'à 2010

	2006	2007	2008	2009	2010
Scénario Volontariste	1.467 MWc	2.179 MWc	3.130 MWc	4.340 MWc	5.650 MWc
Scénario Modéré	1.467 MWc	1.907 MWc	2.479 MWc	3.223 MWc	4.189 MWc
Scénario AIE	1.467 MWc*	888 MWc	1.035 MWc	1.204 MWc	1.401 MWc

*Pour 2006, le chiffre du marché réel de l'EPIA est indiqué. Pour les années ultérieures, les chiffres sont basés sur l'extrapolation des données de l'AIE.



Towards
a low carbon
future

TECHNOLOGY ROADMAP PHOTOVOLTAIC ENERGY (SET-Plan)

European Commission

SETTING THE SCENE

- **Strategic Energy Technology Plan** (COM(2007) 723 final)
strategic plan to accelerate the development and deployment of cost-effective low carbon technologies, which contain two main pillars:
 - European Industrial Initiatives (EIs)
 - European Energy Research Alliance (EERA)
- **Communication on Investing in the development of low Carbon Technologies** (COM(2009) 519 Final)
explains what we need to finance in what we have to invest and how much it will cost
- **Technology Roadmaps** (SEC(2009) 1295)
Commission proposal based on stakeholders consultation, are meant to guide the implementation of the European Industrial Initiatives (**living document**)

TECHNOLOGY ROADMAP PHOTOVOLTAIC ENERGY

- **Strategic objective:**

To improve the competitiveness and ensure the sustainability of the technology and to facilitate its large-scale penetration in urban areas and as free-field production units, as well as its integration into the electricity grid.

- **Industrial sector objective:**

Establish photovoltaics (PV) as a clean, competitive and sustainable energy technology providing up to 12% of European electricity demand by 2020.

Report on the Solar Europe Industrial Initiative

The Market Analyst:

How realistic is a 12% share of PV electricity:

- 462 TWH, 390 GW cumulative installed
- CAGR of 35% for 12 years needed
- 2013 milestone 30 GW world, 17.5 Europe
- Huge markets and R&D have started outside Europe (US, China, India) keep EU leadership
- More than 35% have been demonstrated
- 100 GW annual installation in 2020

Required:

- Feed-in Tariffs (fine tuned!)
- Grid Management
- World-wide Emission Trading

Technology Scenario by “PV2030 +” Roadmap

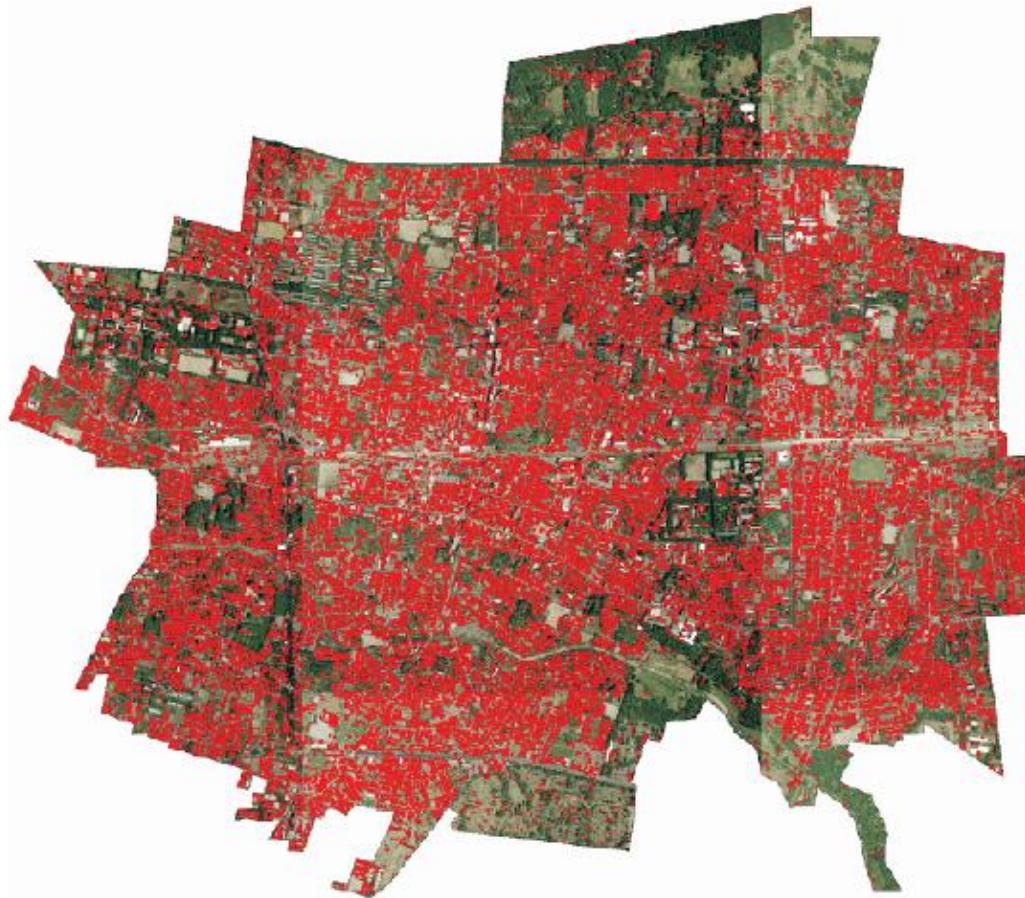
Target Year (R&D)	2010~2020	2020 (2017)	2030 (2025)	2050
Electricity Cost	Residential (23 JPY/kWh)	Industrial (14 JPY/kWh)	Wholesale (7 JPY/kWh)	General (≤ 7 JPY/kWh)
Module Efficiency (Lab. Scale)	16% (Cell 20%)	20% (Cell 25%)	25% (Cell 30%)	Ultra high η module 40%
Domestic Production	0.5~1 GW/Y	2~3 GW/Y	6~12 GW/Y	25~35 GW/Y
Export	~1 GW/Y	~3 GW/Y	30~35 GW/Y	~300 GW/Y
Main Market	Single family houses; Public bldg.	Single/multi-family houses; Public; Business bldg.	Single/multi-family houses; Public; Industry; PhV/EV	Private; Business; Public; Industry; Transport; Agriculture; Electrification

Total area : 11.33 km²

Number of inhabitants : 110 000

Roof area : 2.73 km² about 20%

Assumption	1	2	3
Total roof area [km ²]	2.73	2.73	2.63
Available area [km ²]	2.73	1.23	1.44
Possible capacity[MW]	409.5	184.5	216.1
Annual output energy [GWh]	453.6	204.4	225.7



1 50 MW /km²

Potential for 62 000 houses
With 3621 kWh/home/year

Figure 8: Result image in Koganei city

Merci pour votre attention

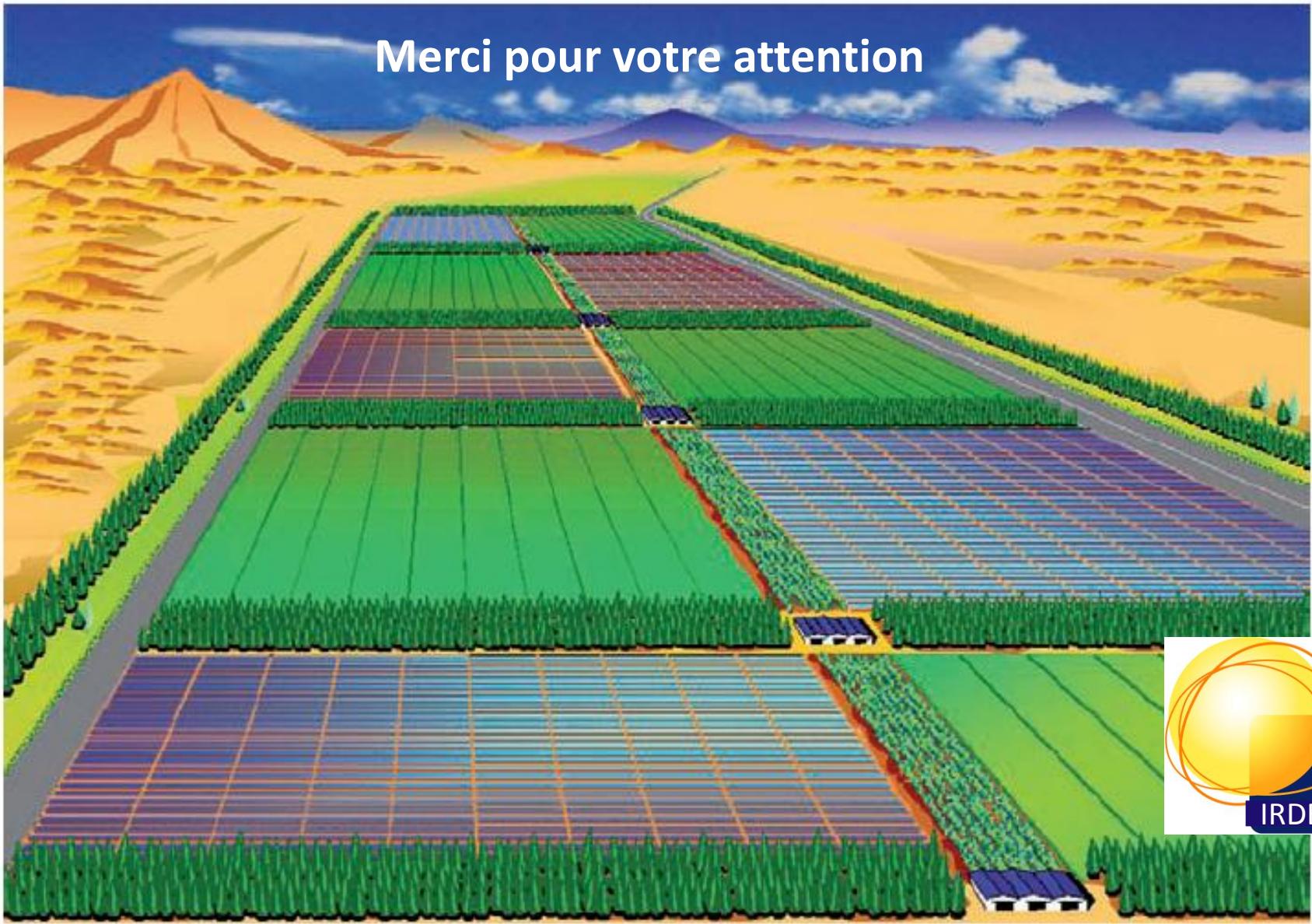


FIGURE 20

Une prospective japonaise : l'énergie photovoltaïque à très grande échelle (Very Large Scale Photovoltaics).
Source : Energy from the desert, Feasability of a very large scale photovoltaic generation systems (VLS-PV)
Ed. K. Kurokawa, James & James, 2003.