The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

ICTP Experts Meeting on "Science & Renewable Energy"
January 15 - 18, 2007

Venue: ICTP Adriatico Guest House - Lundqvist Lecture Hall

310/1905

"Photovoltaics: Current Trends & Vision to 2030"

F. Ferrazza
EniTechnologies Spa
Rome, Italy

Photovoltaics:
current trends and vision to 2030

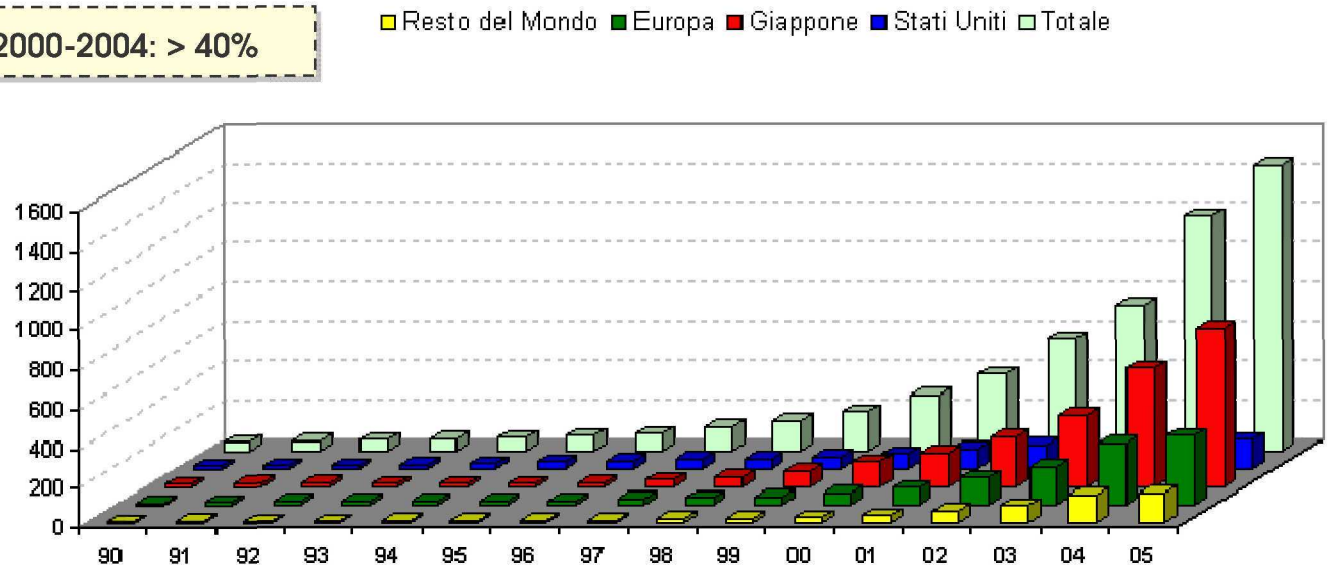
F.Ferrazza

Eni S.p.A., P.le E. Mattei 1, Italy

francesca.ferrazza@eni.it

Module worldwide production

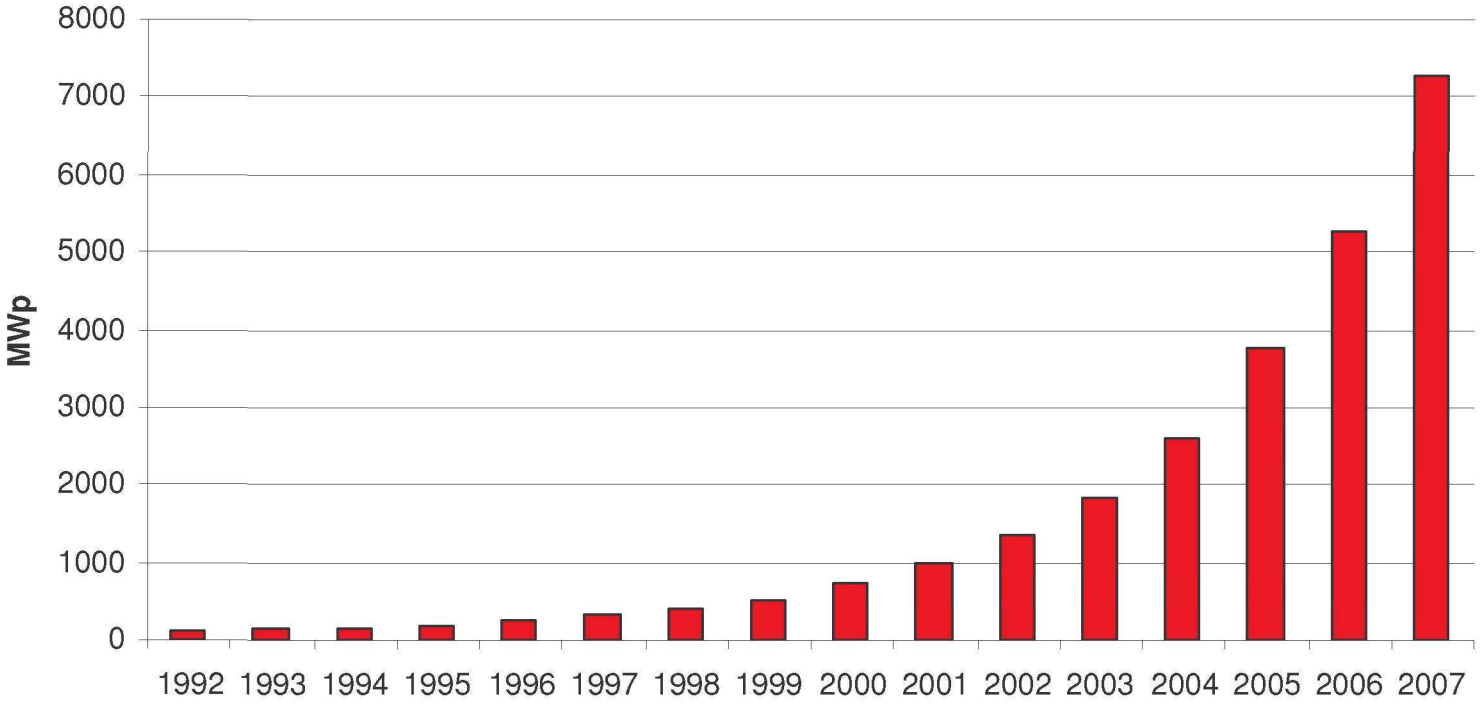
- CAGR 2000-2004: > 40%



	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Resto del Mondo	5	5	5	4	6	6	10	9	19	21	23	33	56	84	139	150
Europa	10	13	16	17	22	20	19	30	34	40	61	86	135	193	314	350
Giappone	17	20	19	17	17	16	21	35	49	80	129	171	251	364	602	800
Stati Uniti	15	17	18	22	26	35	39	51	54	61	75	100	121	103	139	150
Totale	47	55	58	60	69	78	89	126	155	201	288	390	562	744	1194	1450
Crescita annua (%)		19	5	4	15	12	14	42	23	30	43	36	44	32	60	21

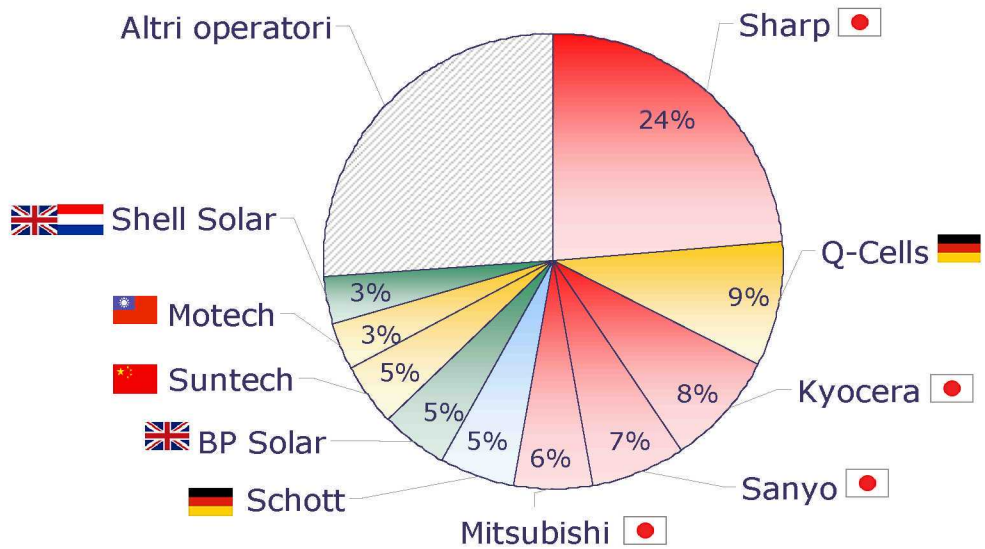
Fonte: EU COMMISSION PV STATUS REPORT 2005

Cumulative installed power



Source: IEA REPORT PVPS t1-14 2005

Top Players



Gruppo attivo nel settore:

- elettronica
- Oil&Gas
- vetro

Società specializzata nel fotovoltaico

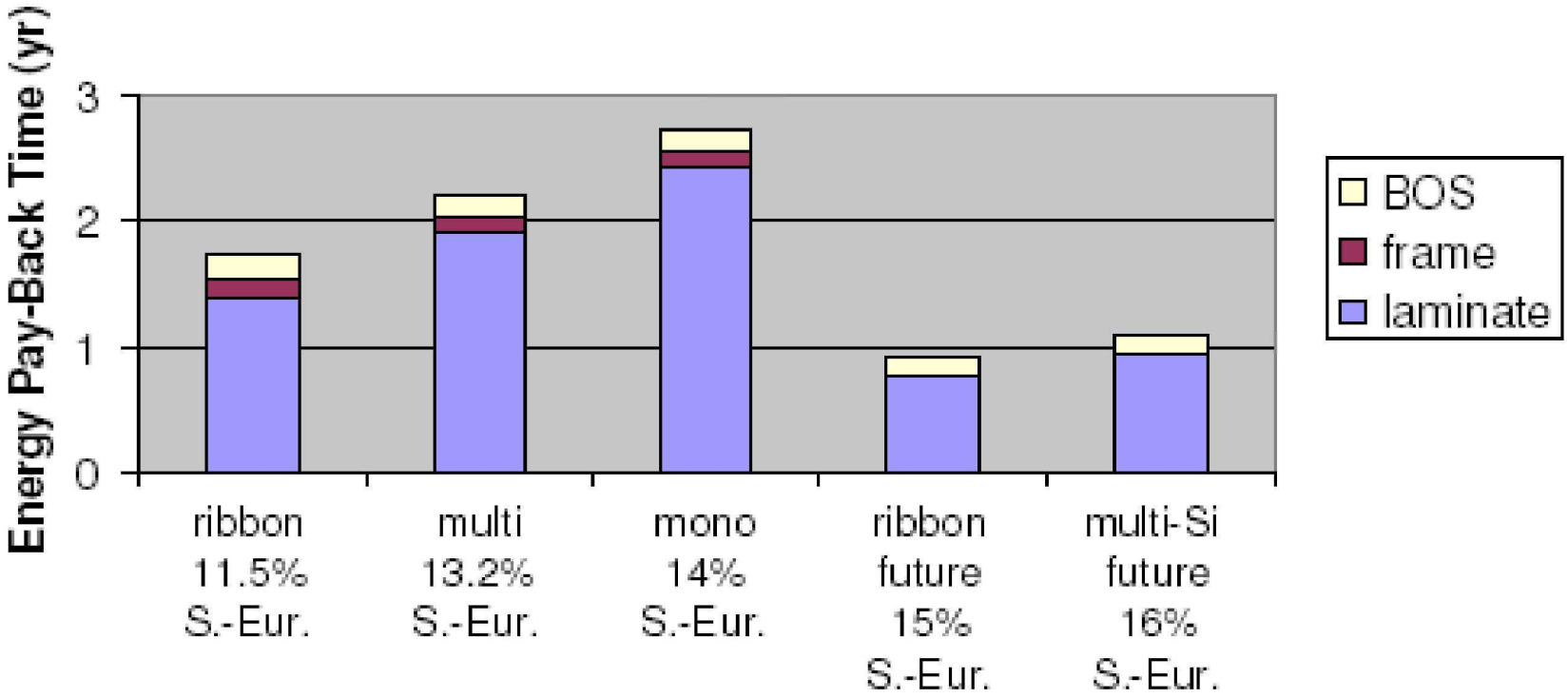
* Nel 2006 Shell Solar ha venduto gran parte dei suoi impianti a SolarWorld (Germania, specializzata nel fotovoltaico)

Energy pay-back time can be less than two years

Località	Parametro	Tetto (inclinato)	Facciata (verticale)
Roma	Produzione annua, kWh	1.300	860
	EPBT,mesi	23	35
(1.552 kWh/m2/anno)	Fattore di ritorno energetico	14	9
Milano	Produzione annua, kWh	1.000	680
	EPBT, mesi	30	44
(1.251 kWh/m2/anno)	Fattore di ritorno energetico	11	7

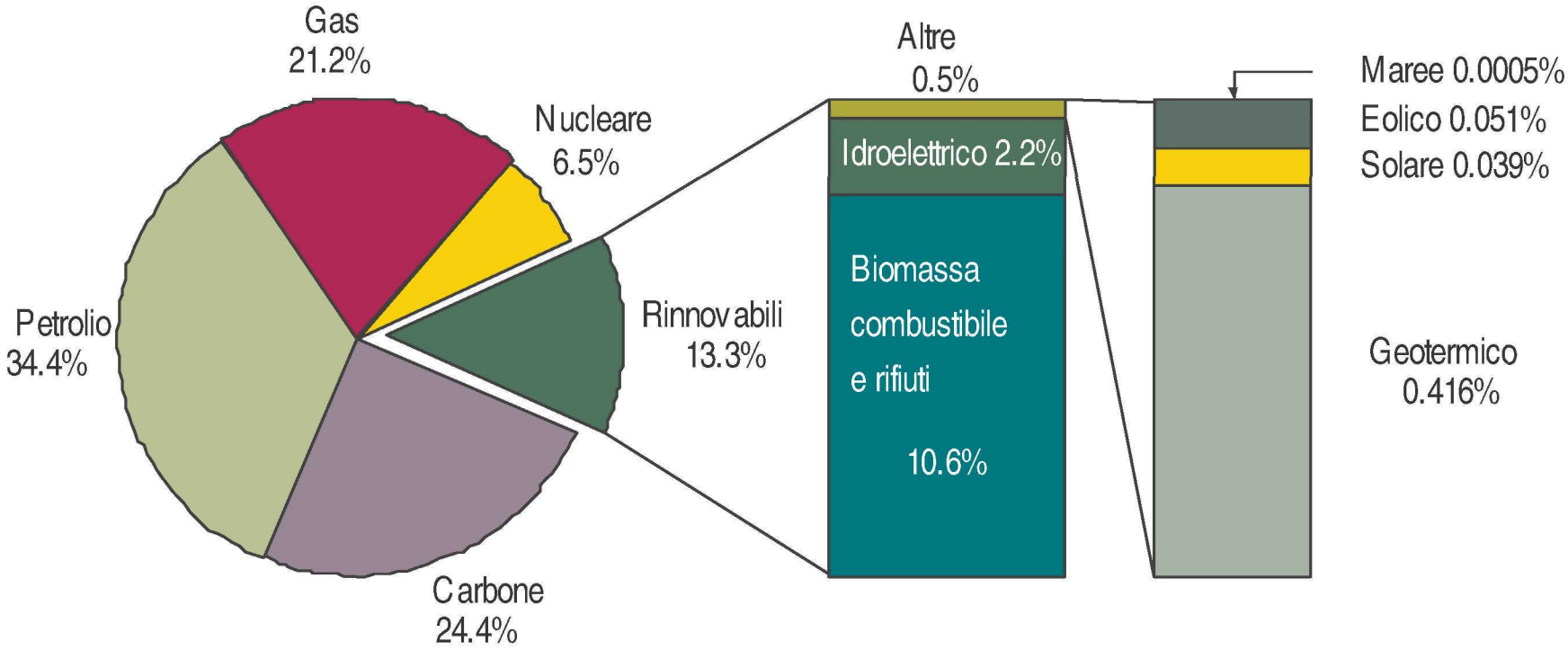
Energy Pay-Back Time of PV systems

(grid-connected, roof-top PV system;
irradiation 1700 kWh/m2/yr)



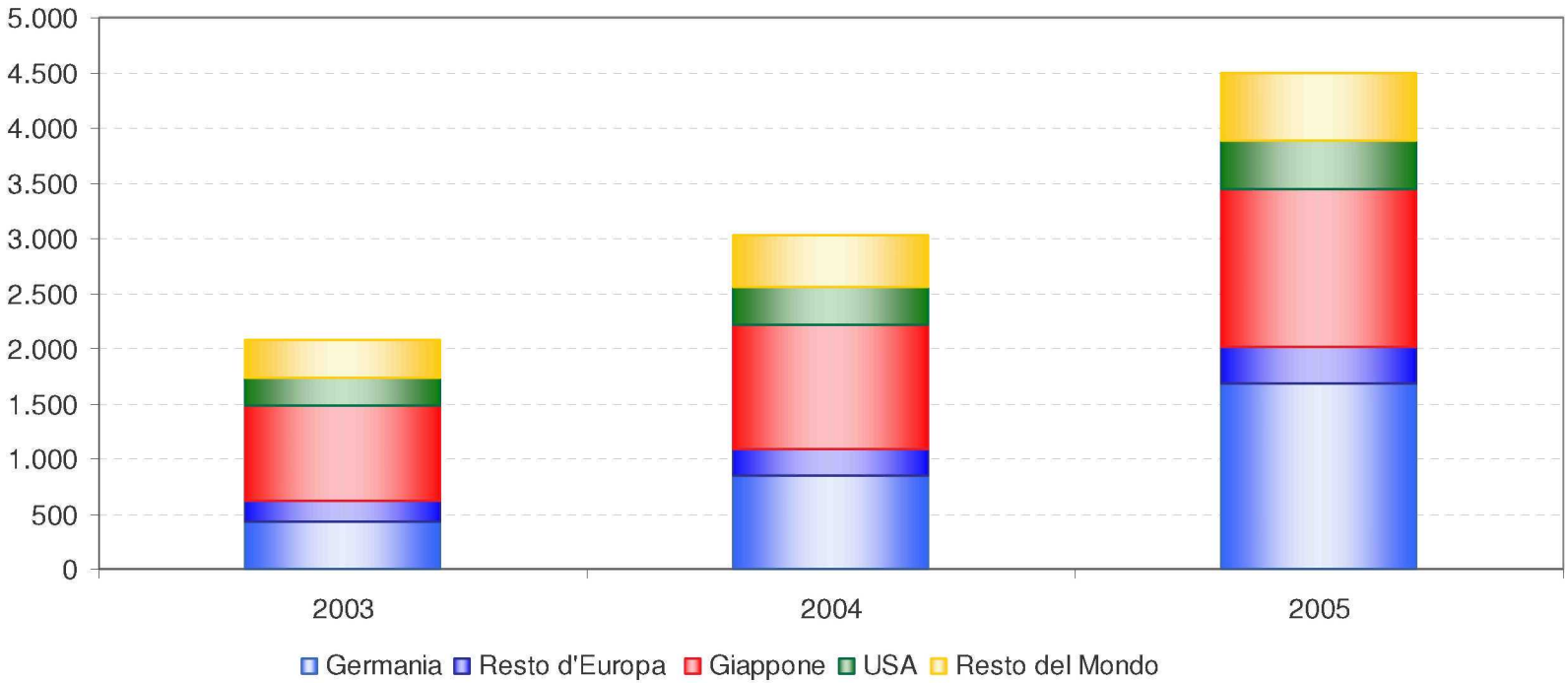
source E. Alsema, PV Platform and Crystal Clear

Solar is a minor player in the global energy sector

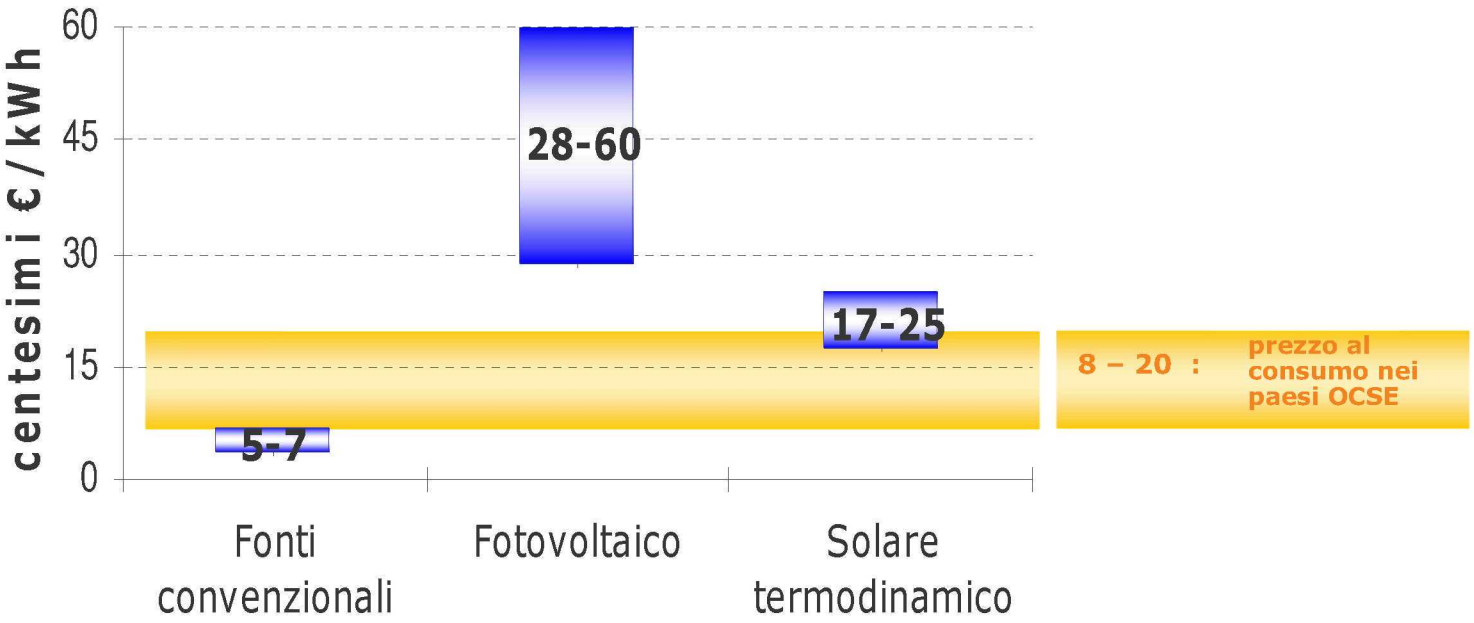


Eni's Way

Market is strongly regional-based

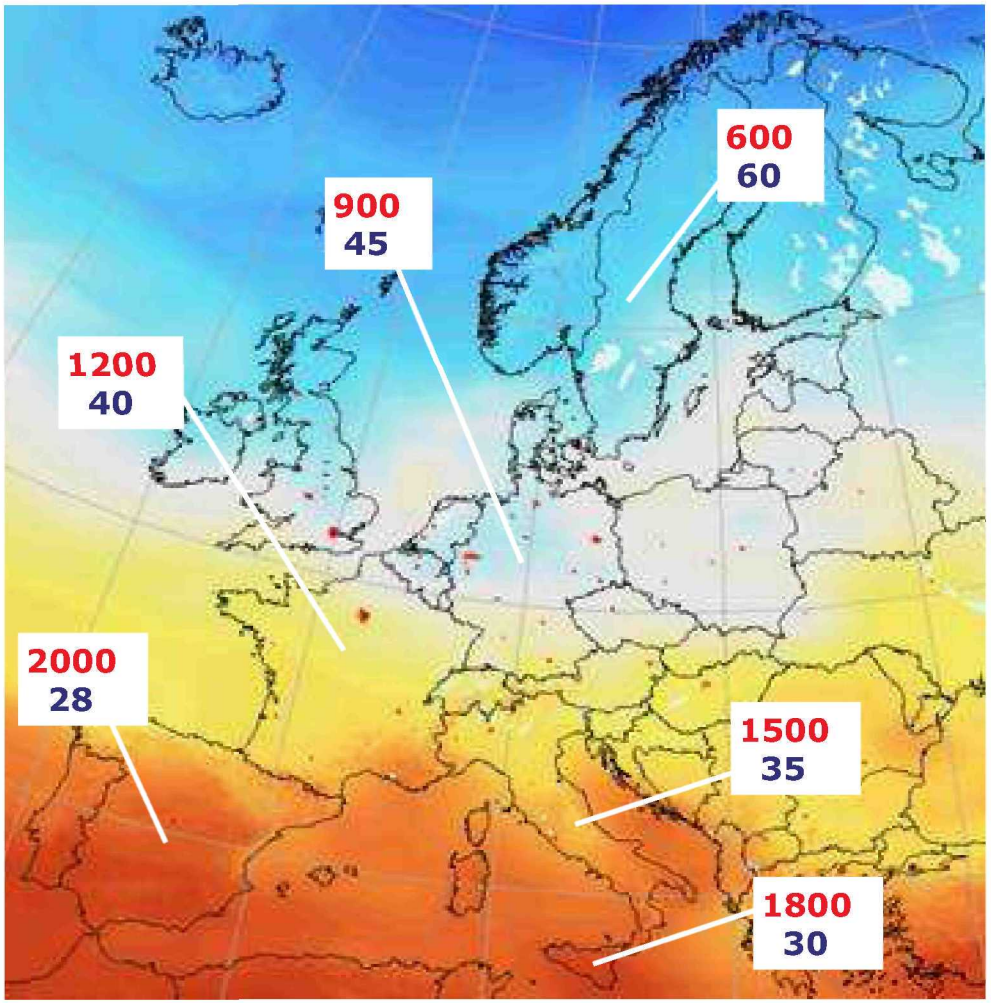


Solar in general is more expensive than conventional fossil fuel based electricity



Eni's Way

Location-dependent generation costs

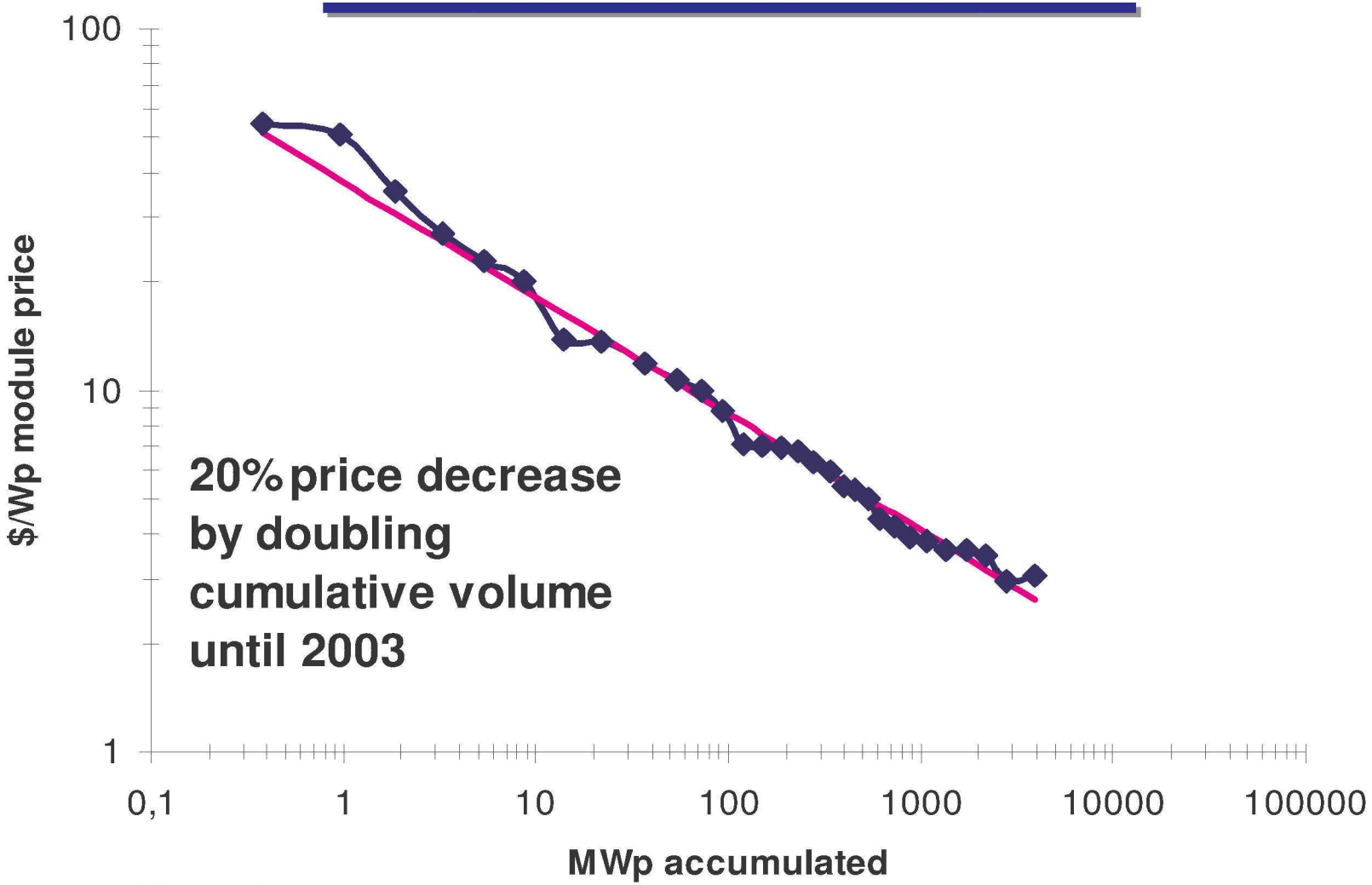


Flusso di energia radiante incidente in un anno (kWh/m^2)

Produzione: kWh_{anno}/kW

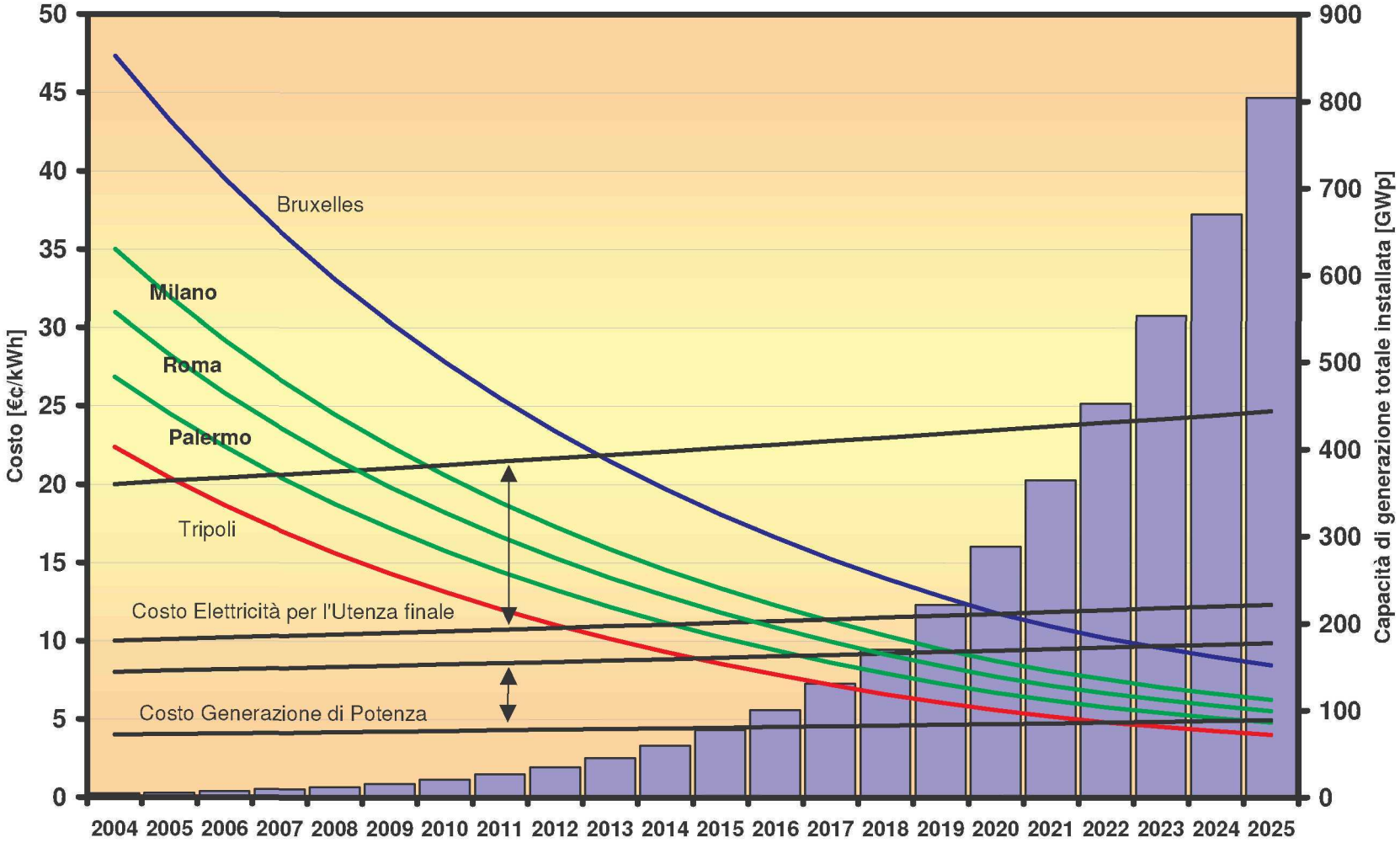
Costo: €c/kWh

Price Learning curve



source EPIA website

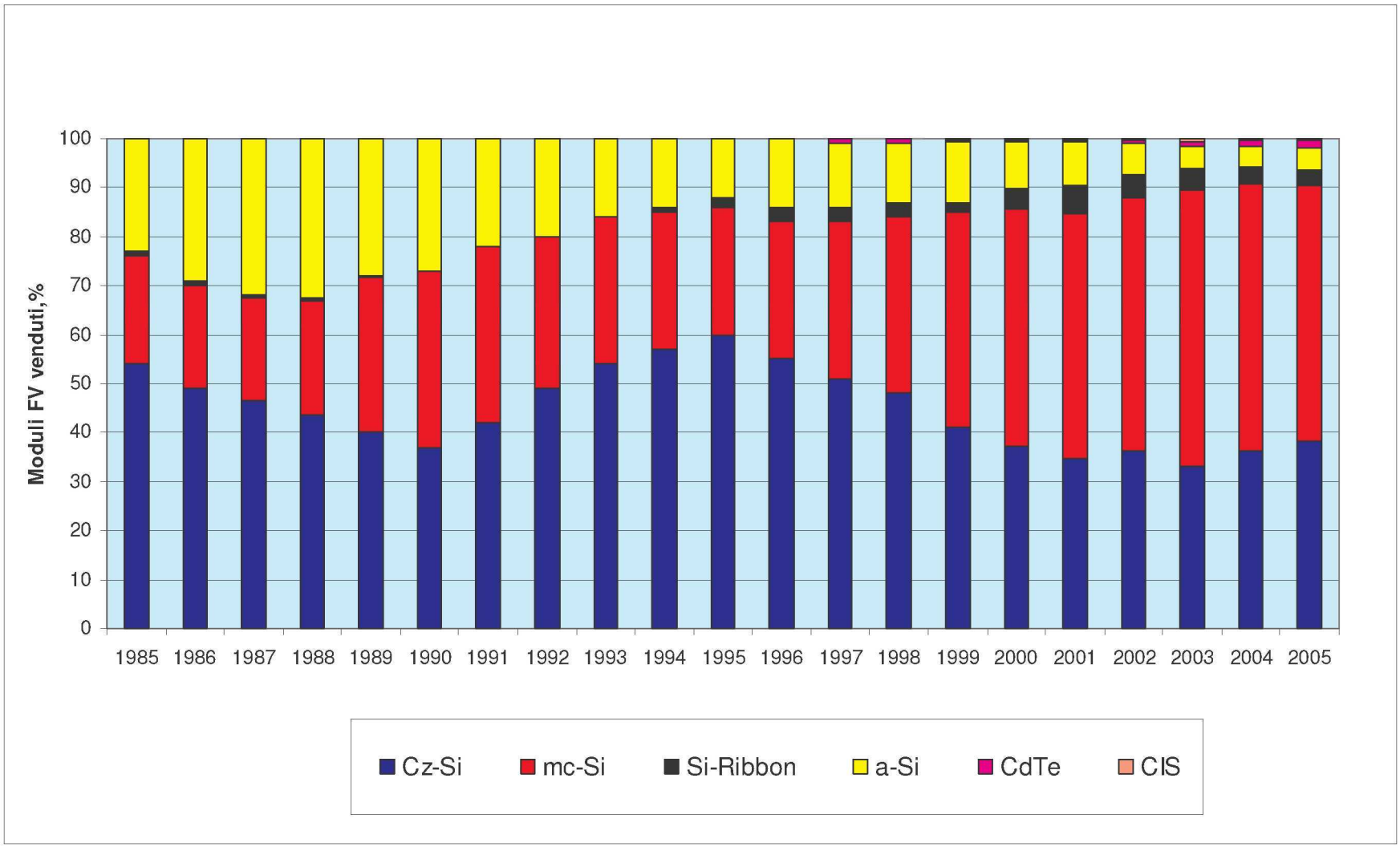
Evoluzione del Mercato FV



Source: G. Agostinelli, M. Acciarri, F. Ferrazza, Le Scienze, May 06

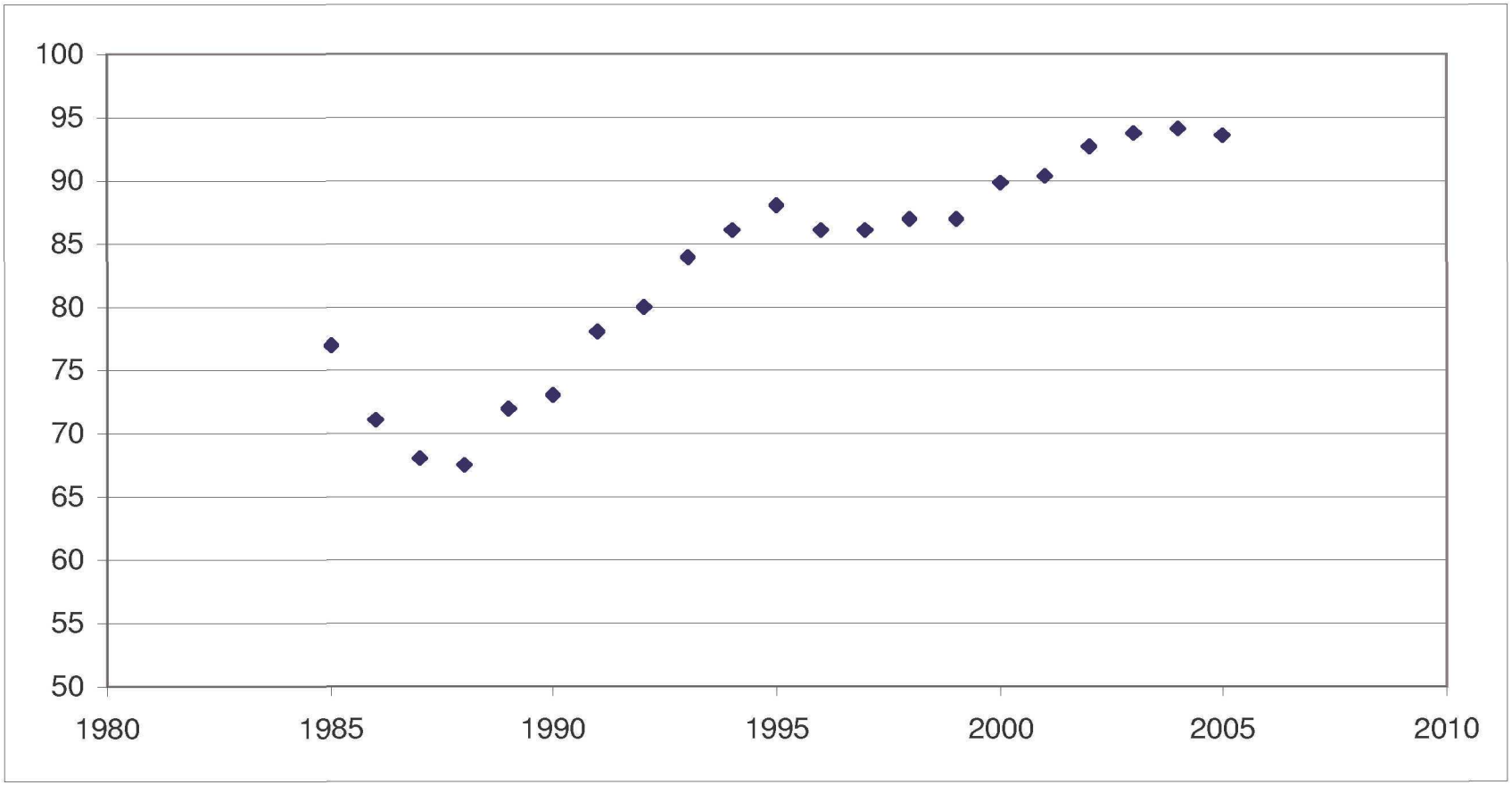
Market by technology

source JRC PV Status report 2005,
Photon International…



Eni's Way

C-Si share of the PV market



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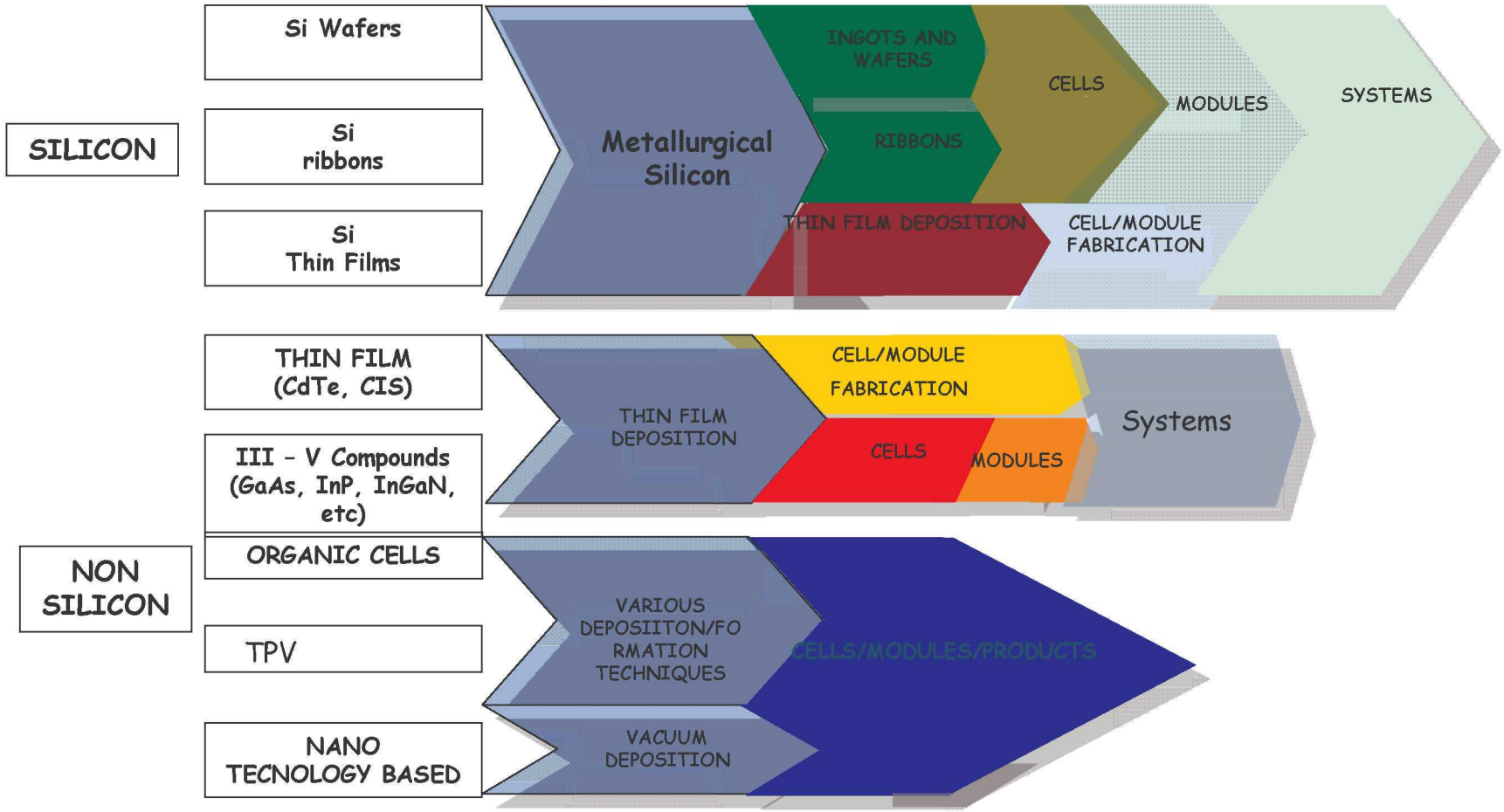
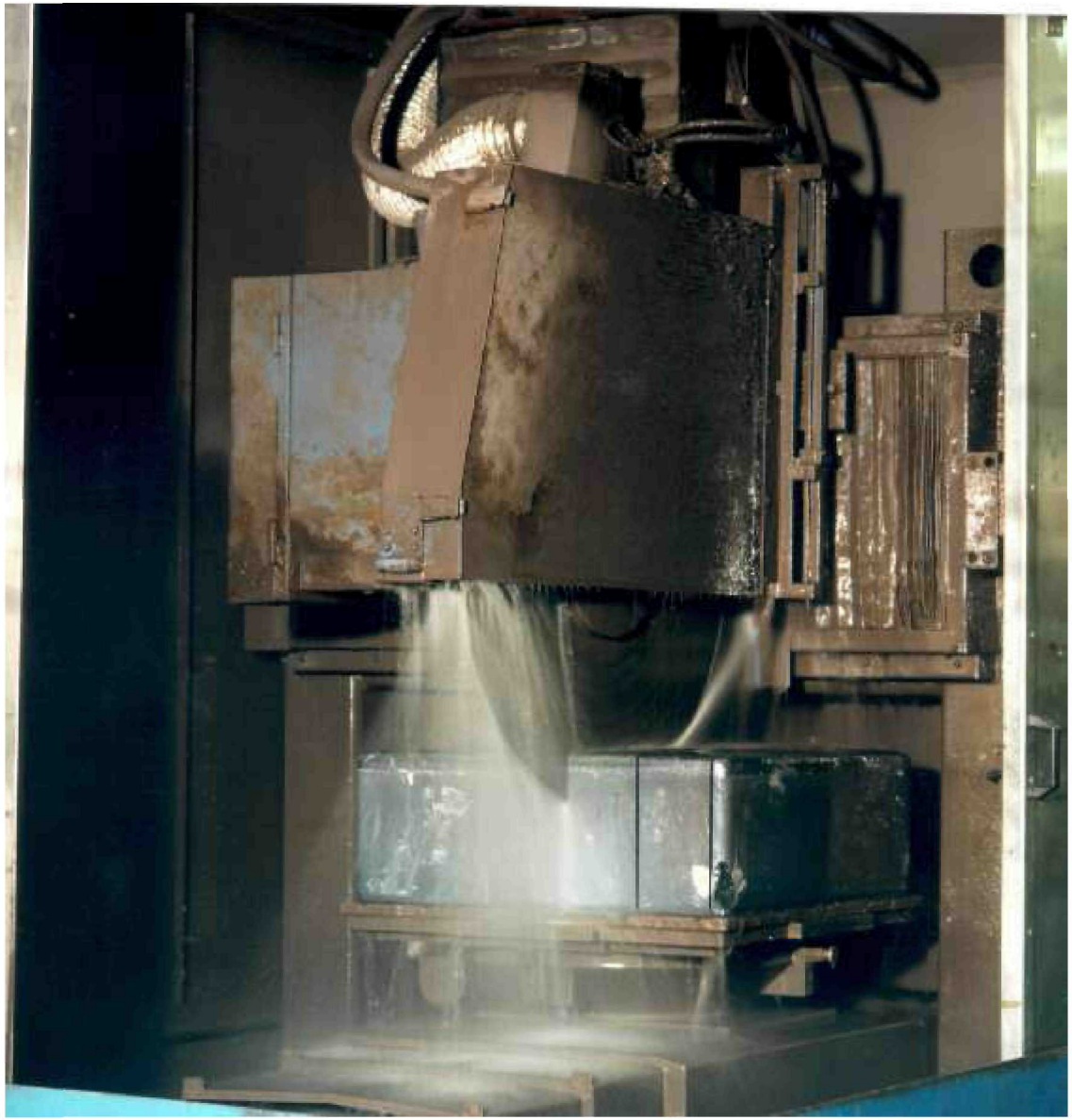
Solar Technologies by materials



Old days...



source EniTecnologie

5 MW/yr – 1990 (Eurosolare, Nettuno)

source EniTecnologie

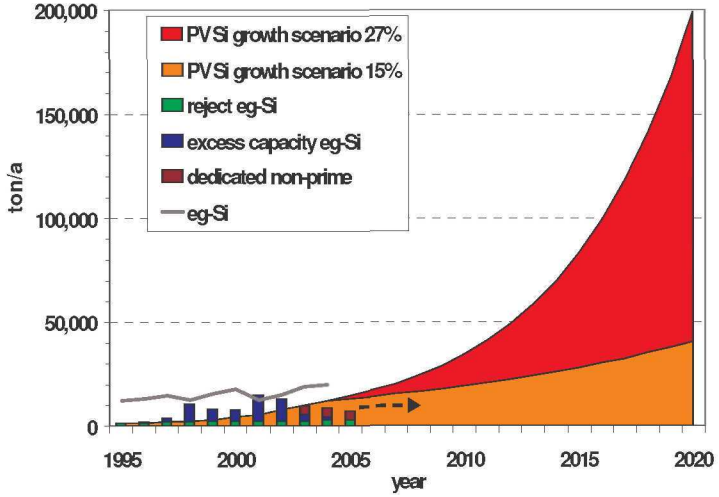
source Q-Cells website

50MW/yr, 2005

source Q-Cells website

String Ribbon manufacturing – source Evergreen website

Long-term outlook

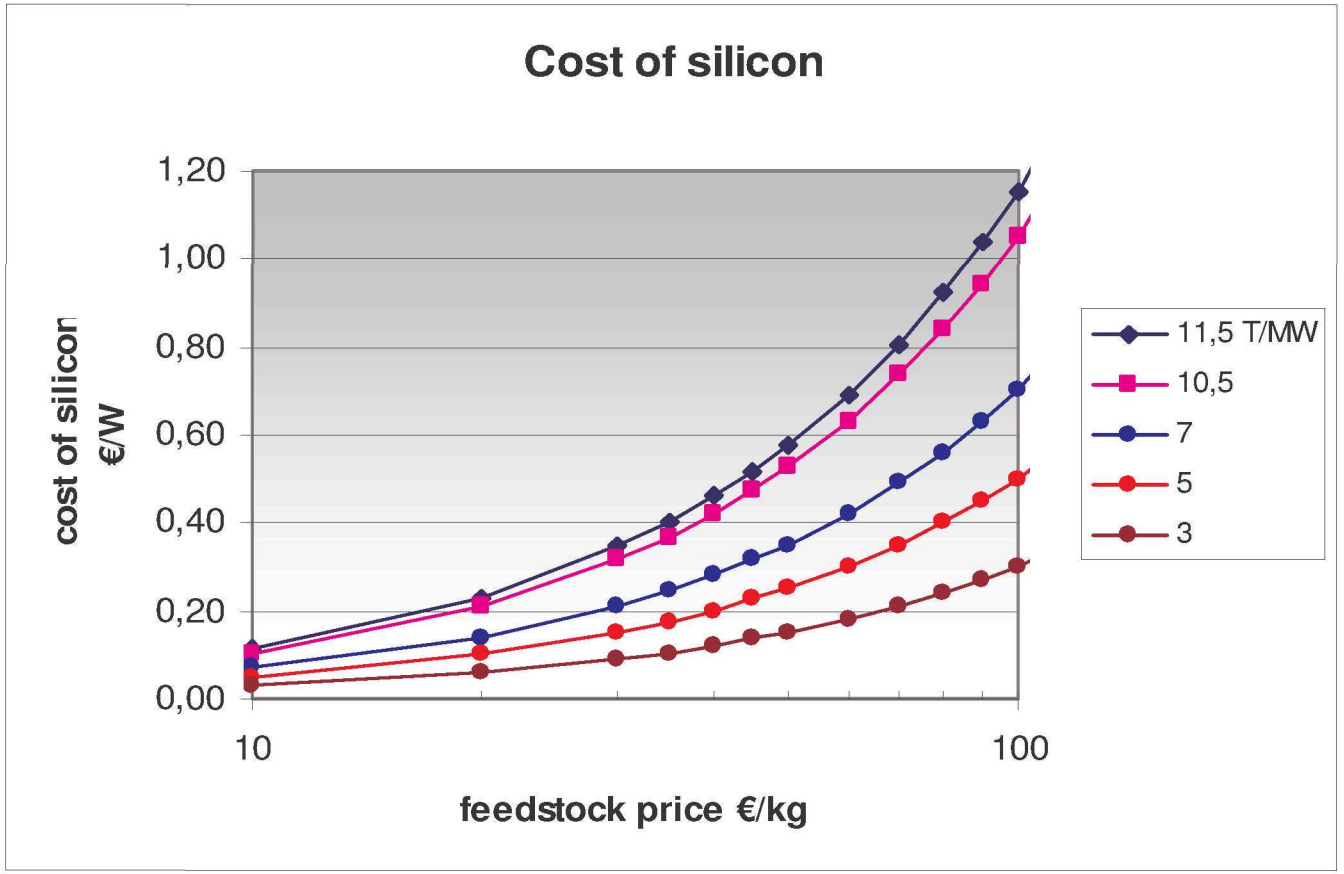


Indicative figures what **could** be the demand for Si by **2020**:

- growth to 45 GWp;
- c-Si 70% of PV production;
- Si consumption 5 g/Wp or less;

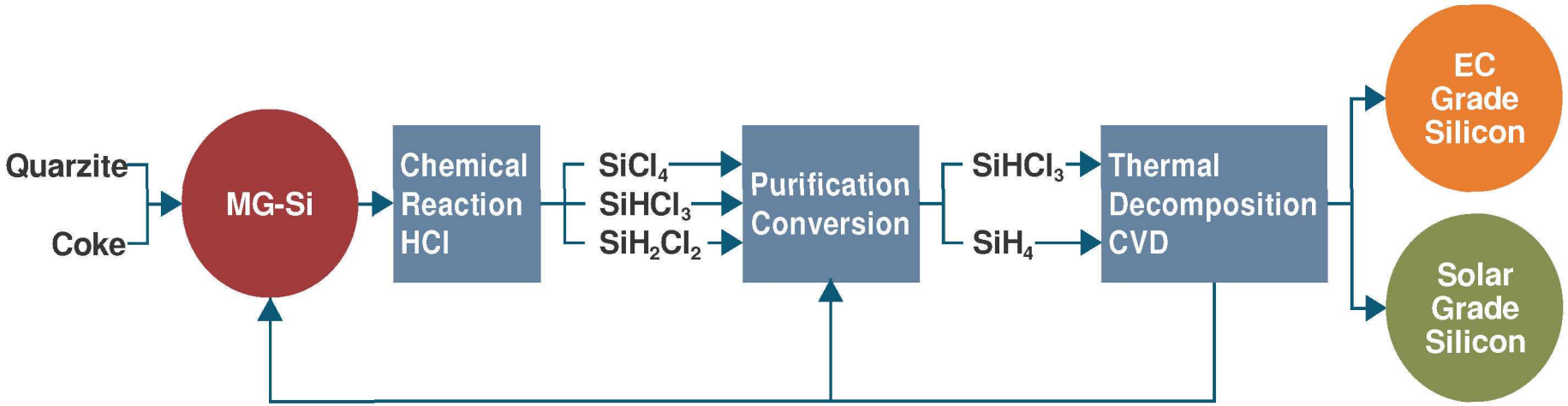
⇒ **Si demand ≈10^5 tons/a**

Silicon price strongly affects cell costs

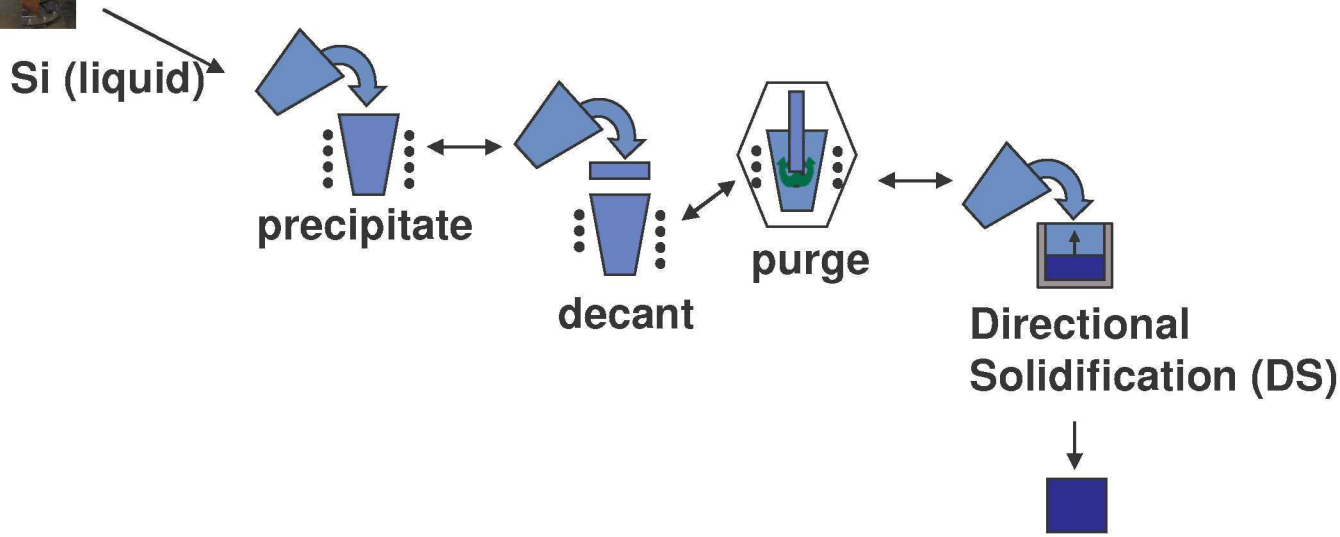


Eni's Way

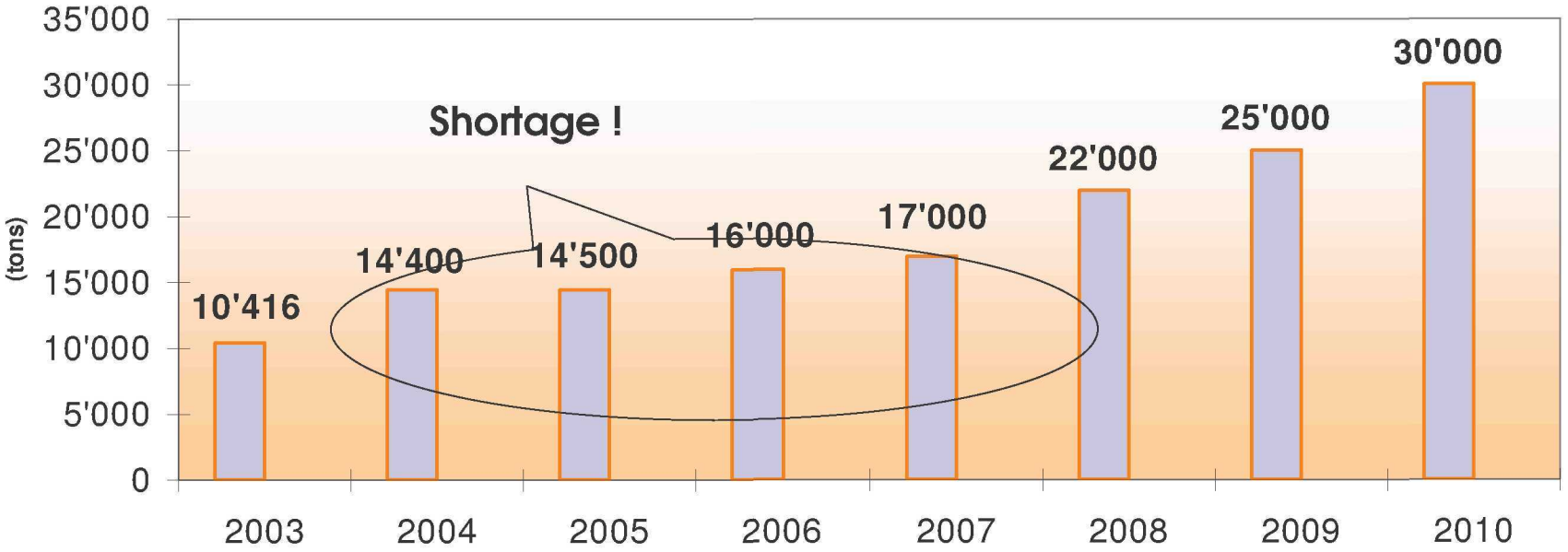
Silicon feedstock production chain



SOLSILC process
Carbon removal/solidification

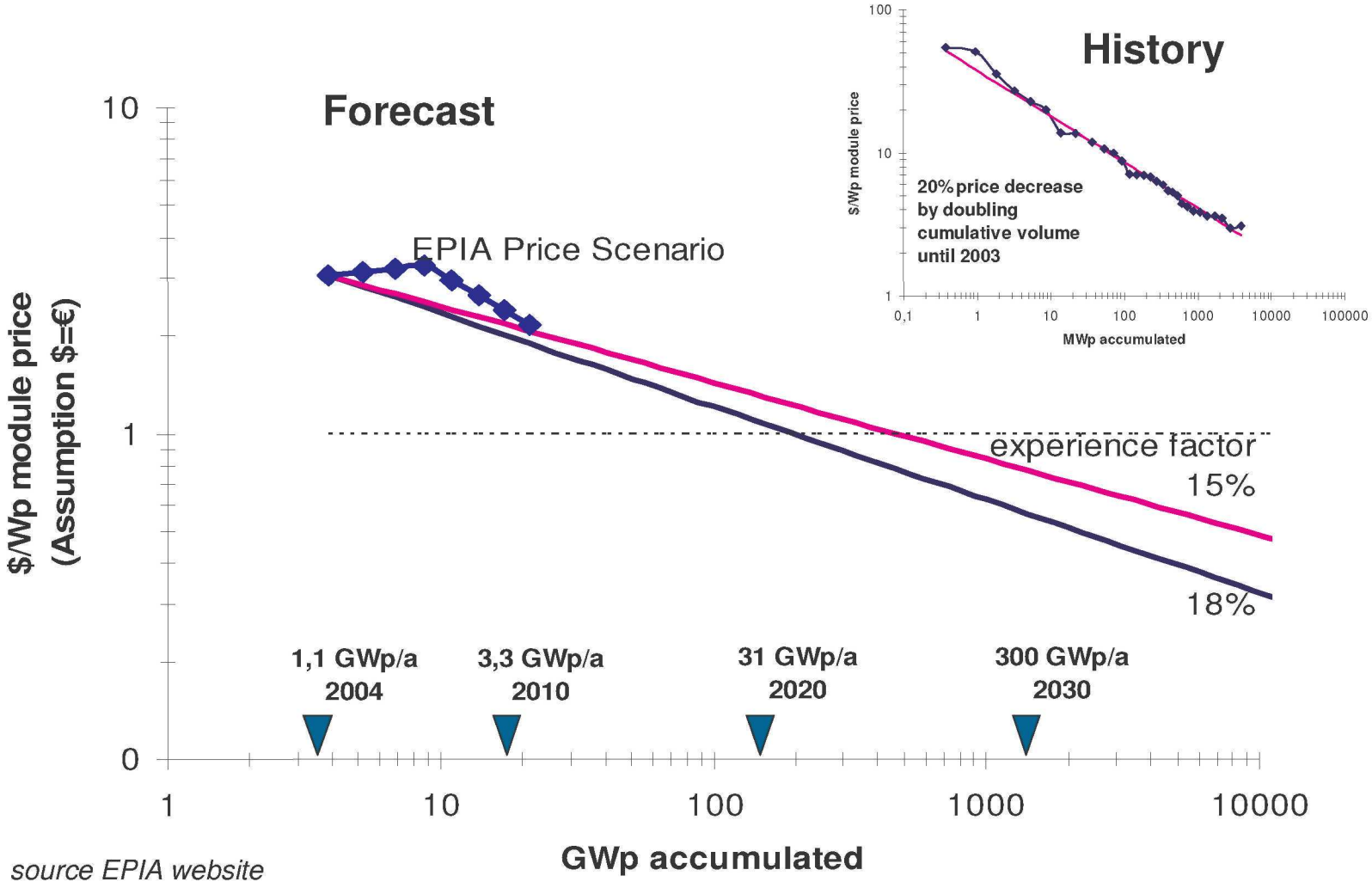


Silicon Feedstock Demand



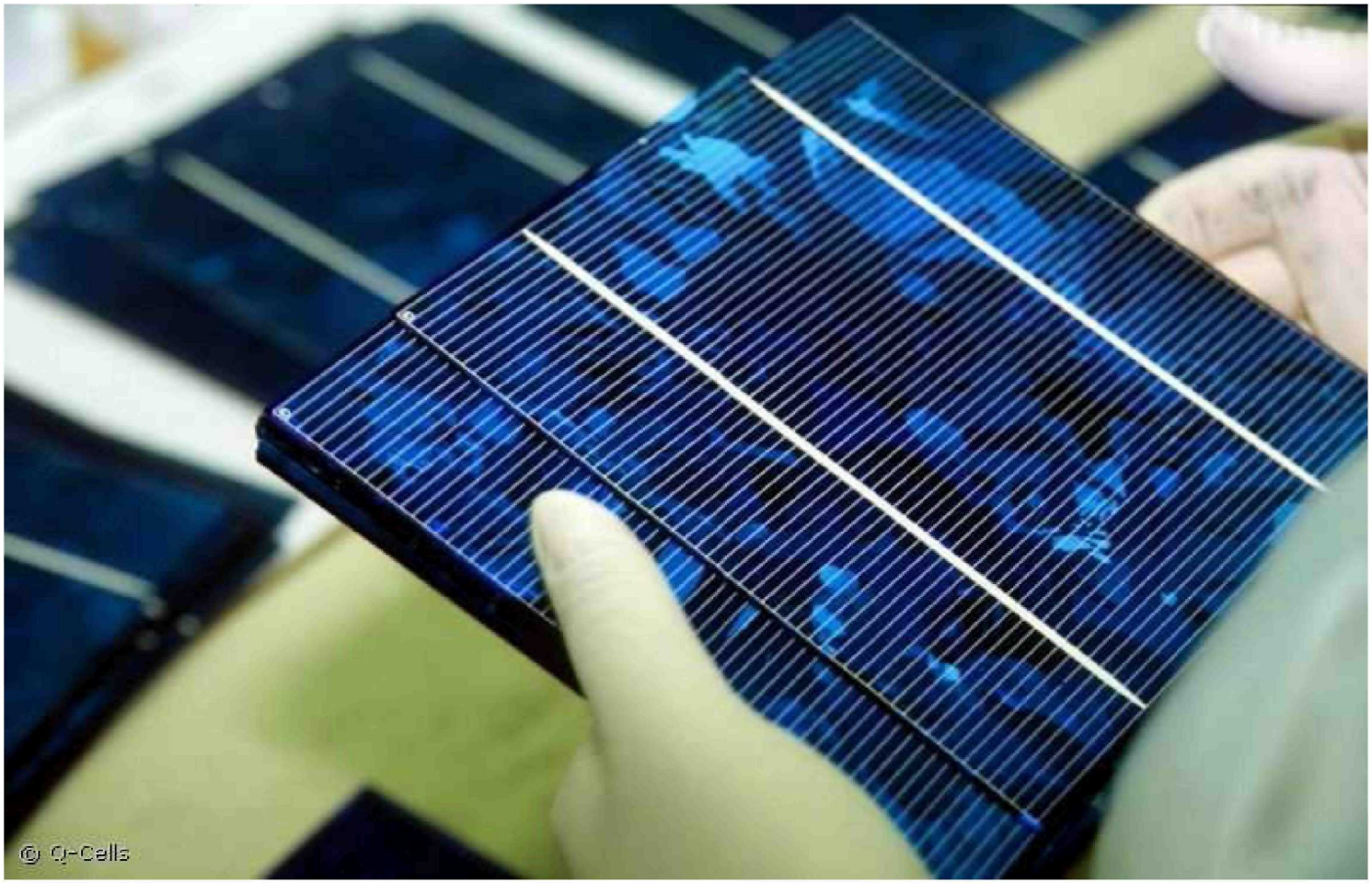
Fonte: Workshop EPIA 22nd of December

Price learning curve



source EPIA website

Discrete and fragile…



source EPIA website

...relatively low efficiency

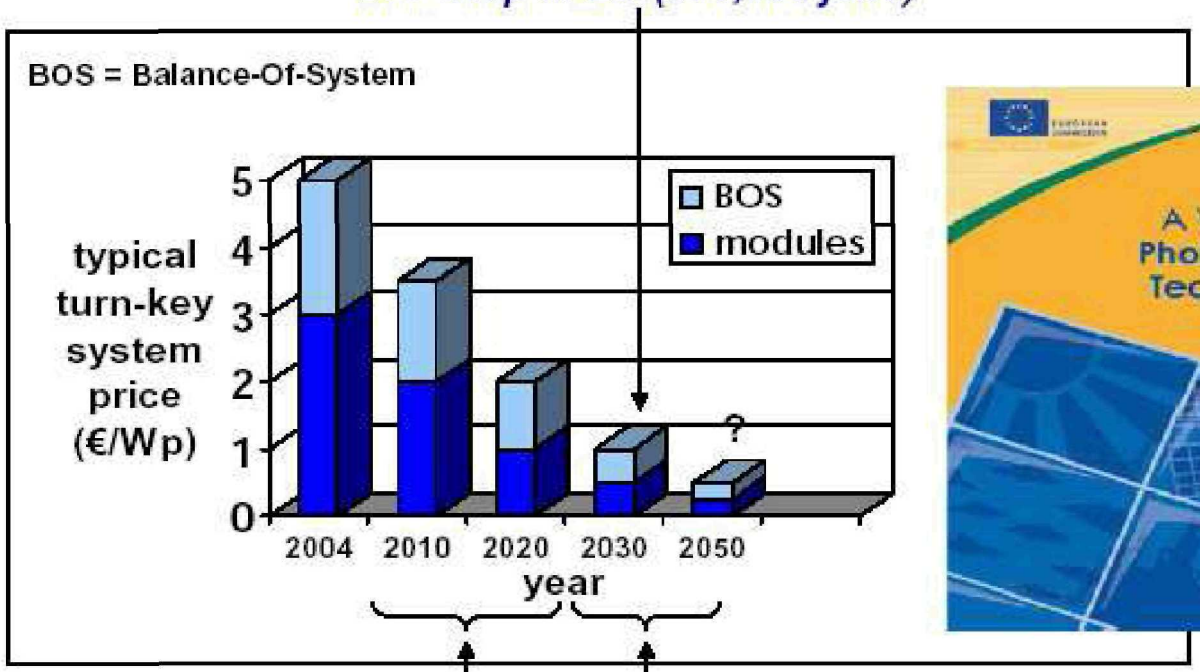
source EPIA website

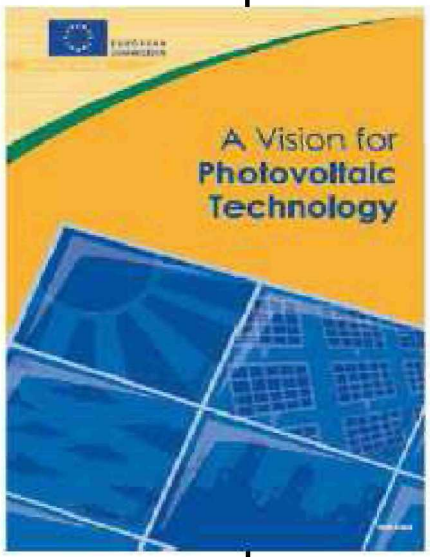
The challenges

PhotoVoltaic TECHNOLOGY PLATFORM

1000 GWp globally

200 GWp in EU (200,000 jobs)

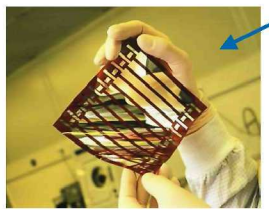


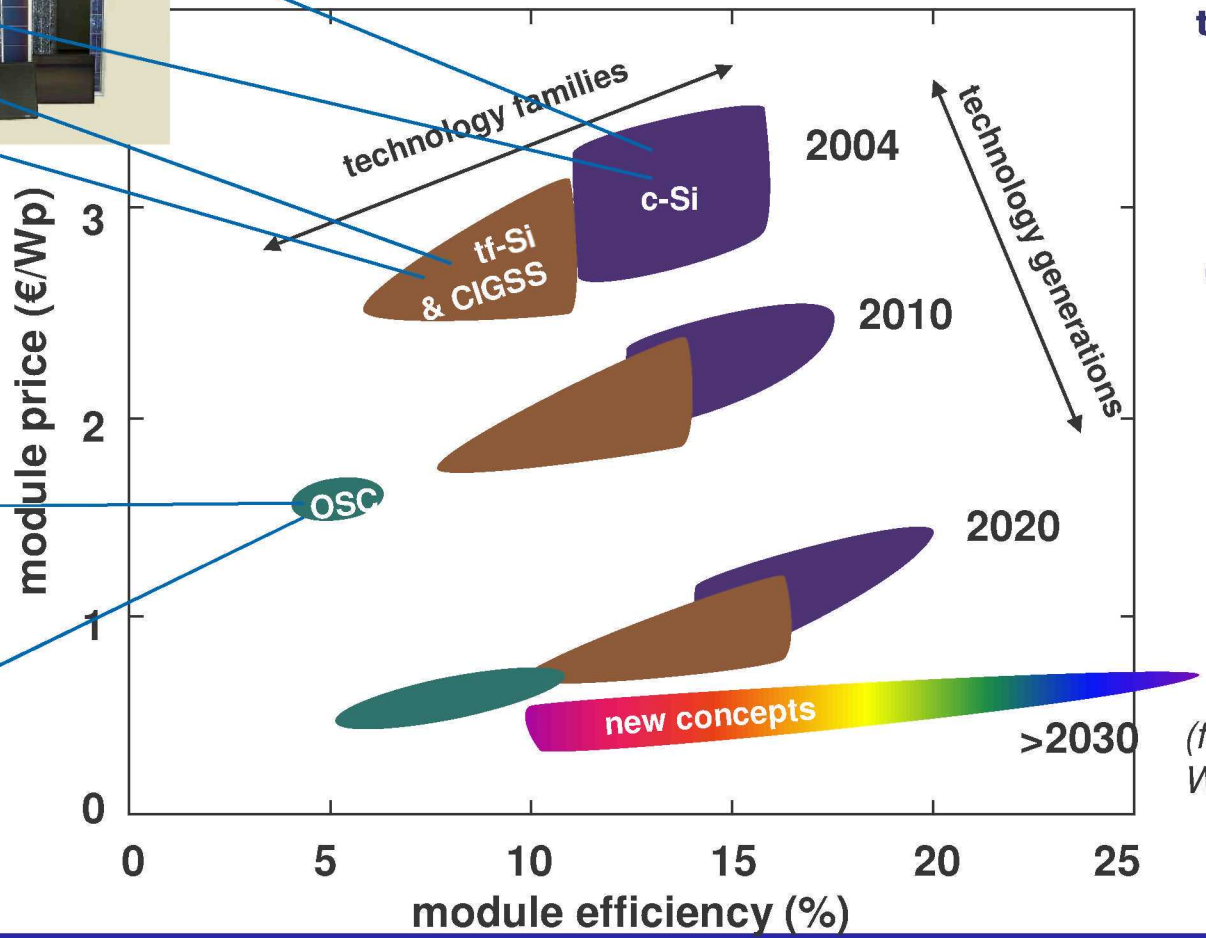


source W. Sinke, PV Platform GA

Eni's Way

possible evolution of module price & performance

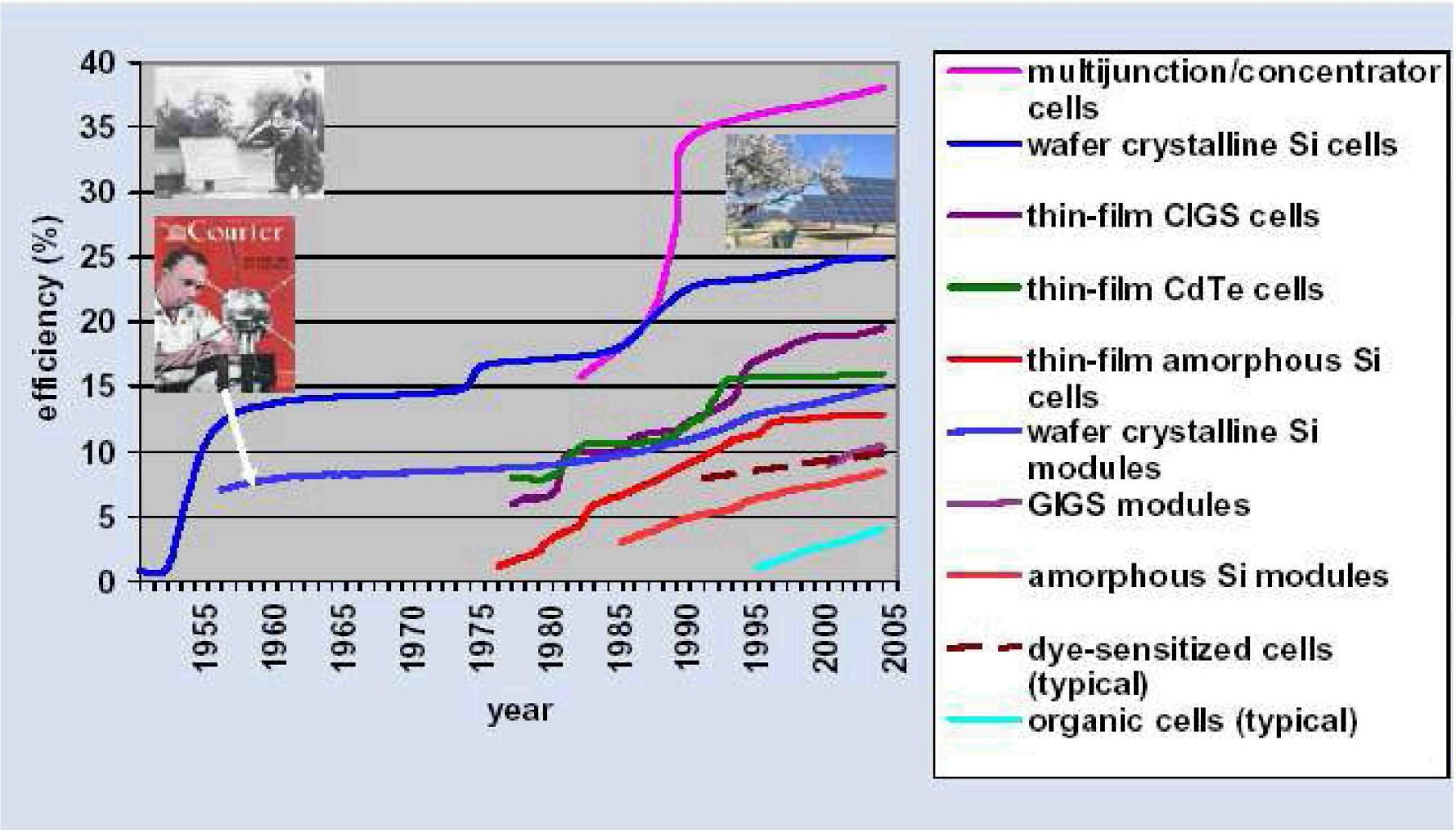




tf-Si = thin-film silicon
CIGSS = copper-indium/gallium-selenium/sulfur
c-Si = wafer-type crystalline silicon
OSC = "organic" solar cells
new concepts = advanced versions of existing technologies & new conversion principles

(free after W. Hoffmann)

Tecnology evlution map



source G. Agostinelli, Imec, Crystal Clear, …

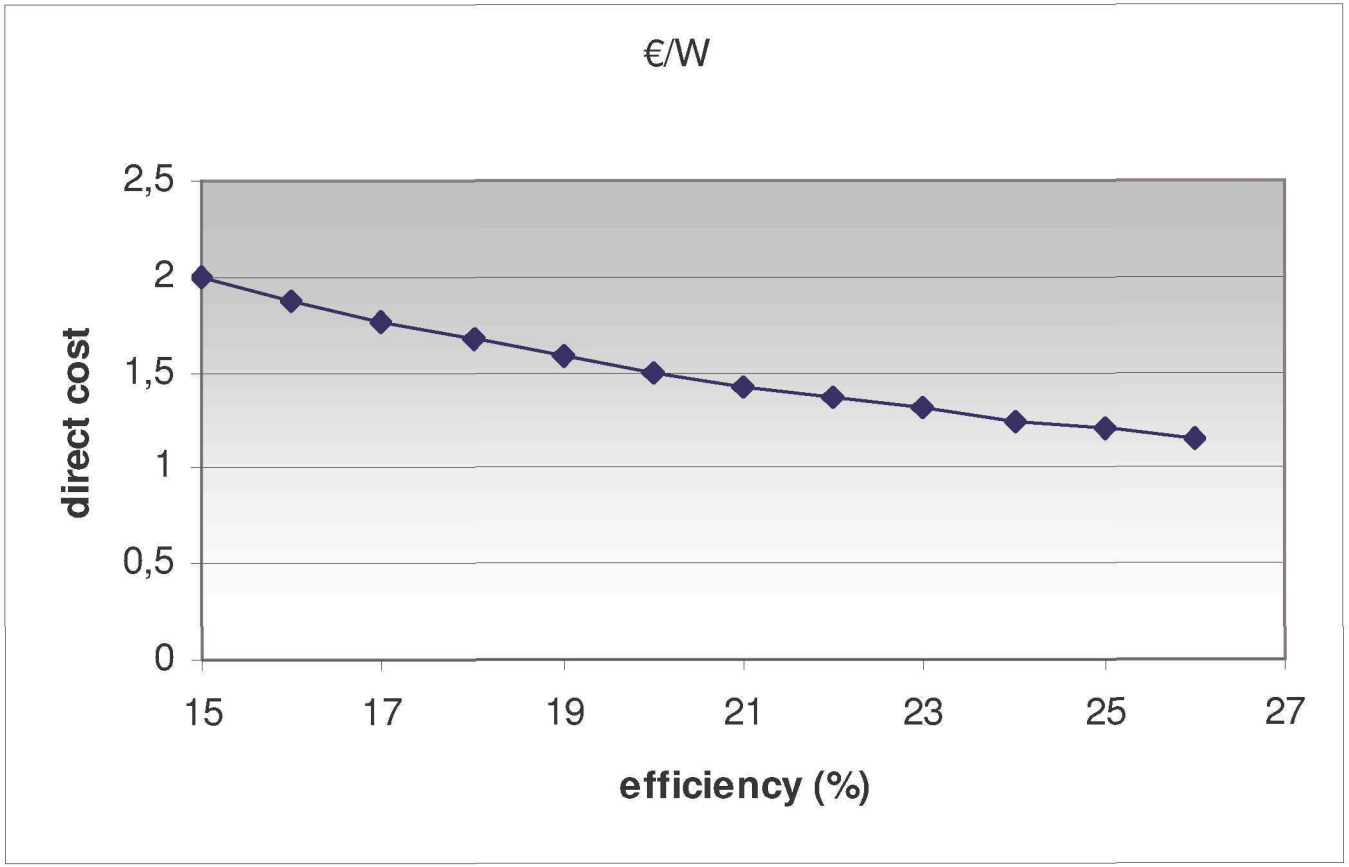
Progress of the overall PV sector

Some important research issues are shared

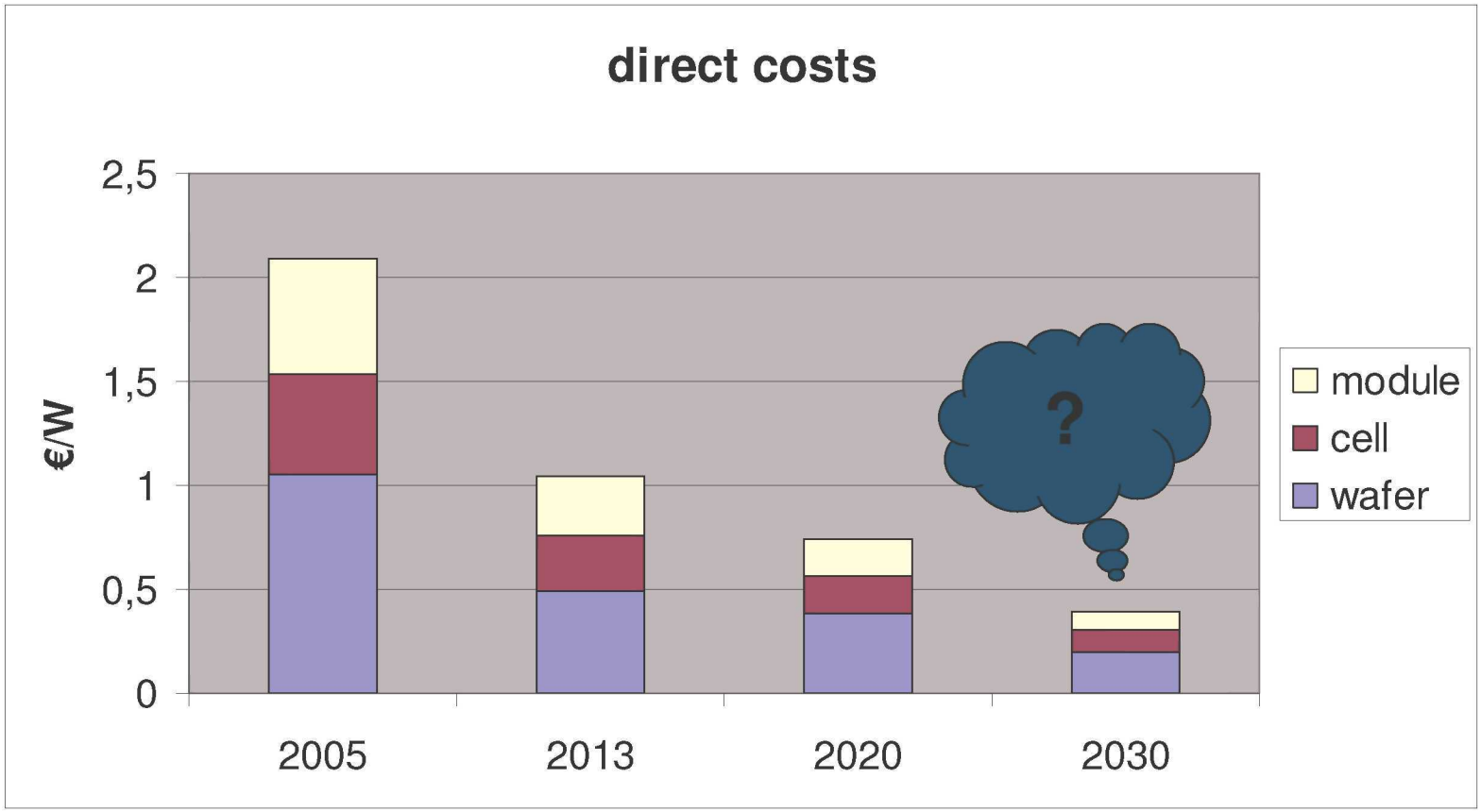
- ***efficiency, stability and lifetime***
- ***materials use (quality & quantity)***
- ***high-throughput manufacturing***
- ***in-process monitoring & control***
- ***environmental sustainability***

source W. Sinke, WG3
PV Platform

Efficiency is an important driver



Cost reductions + increased efficiency + higher productivity + lower EPBT +…



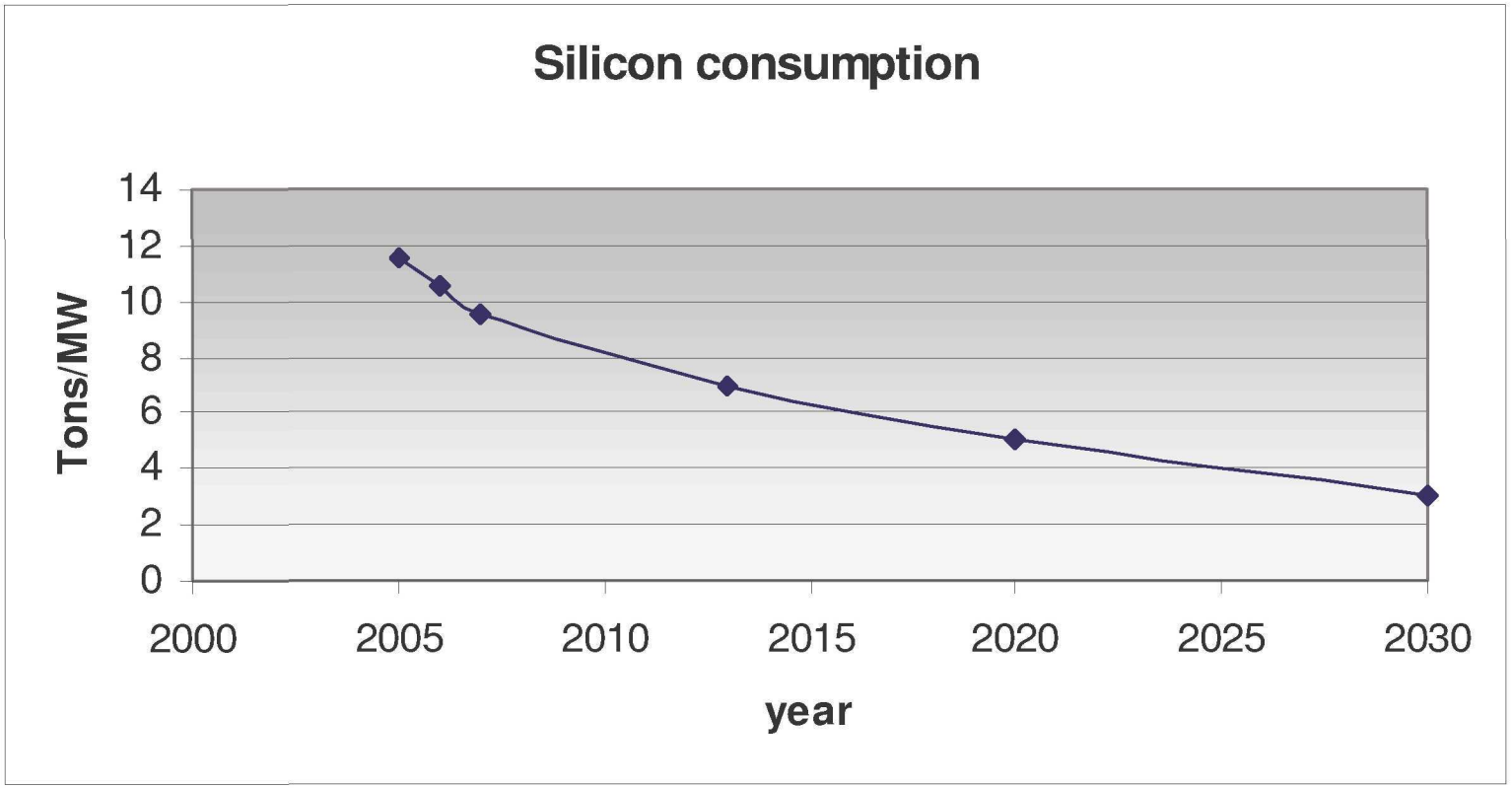
Eni's Way

Wafer-based crystalline silicon

- high efficiency
- low overall silicon consumption
- feedstock quality / cost optimum
- low-cost encapsulation materials and module concepts

source W. Sinke, WG3 PV Platform

Silicon consumption reduction as a first measure for cost reduction



Thin!

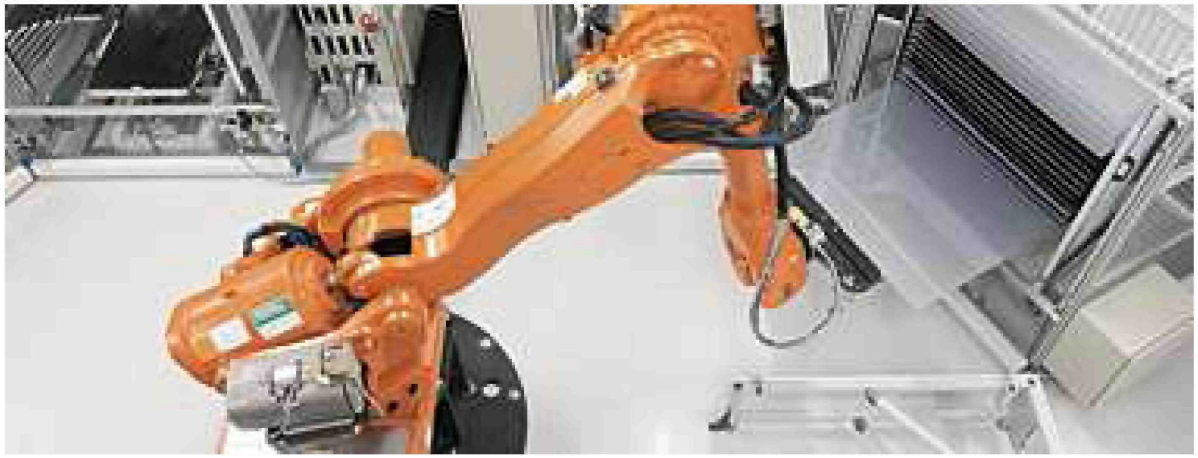
Thin RGS ribbon – source ECN website

Thin and efficient!

Highly efficient solar cells on an extremely thin and flexible wafer (40 µm). The cells were produced with LFC (laser-fired contacts) technology.

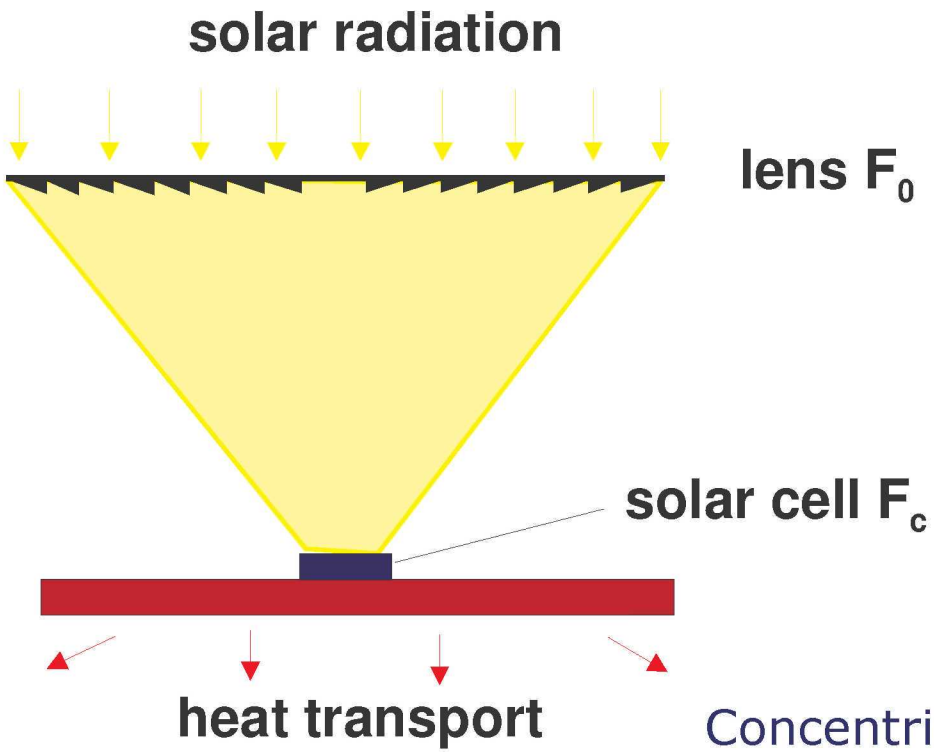
source FHG-ISE website

New thin film manufacturing facility - silicon on glass



Csg solar, Germany

Concentrators – new initiatives



Concentrix Solar GmbH (D)

www.concentrix-solar.de

High efficiency multijunction cells for space applications

Spectrolab's record cells > 40% efficient!

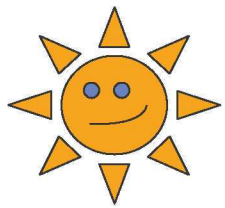
The Silicon shortage has

- contributed to bump in price learning curve

But has also

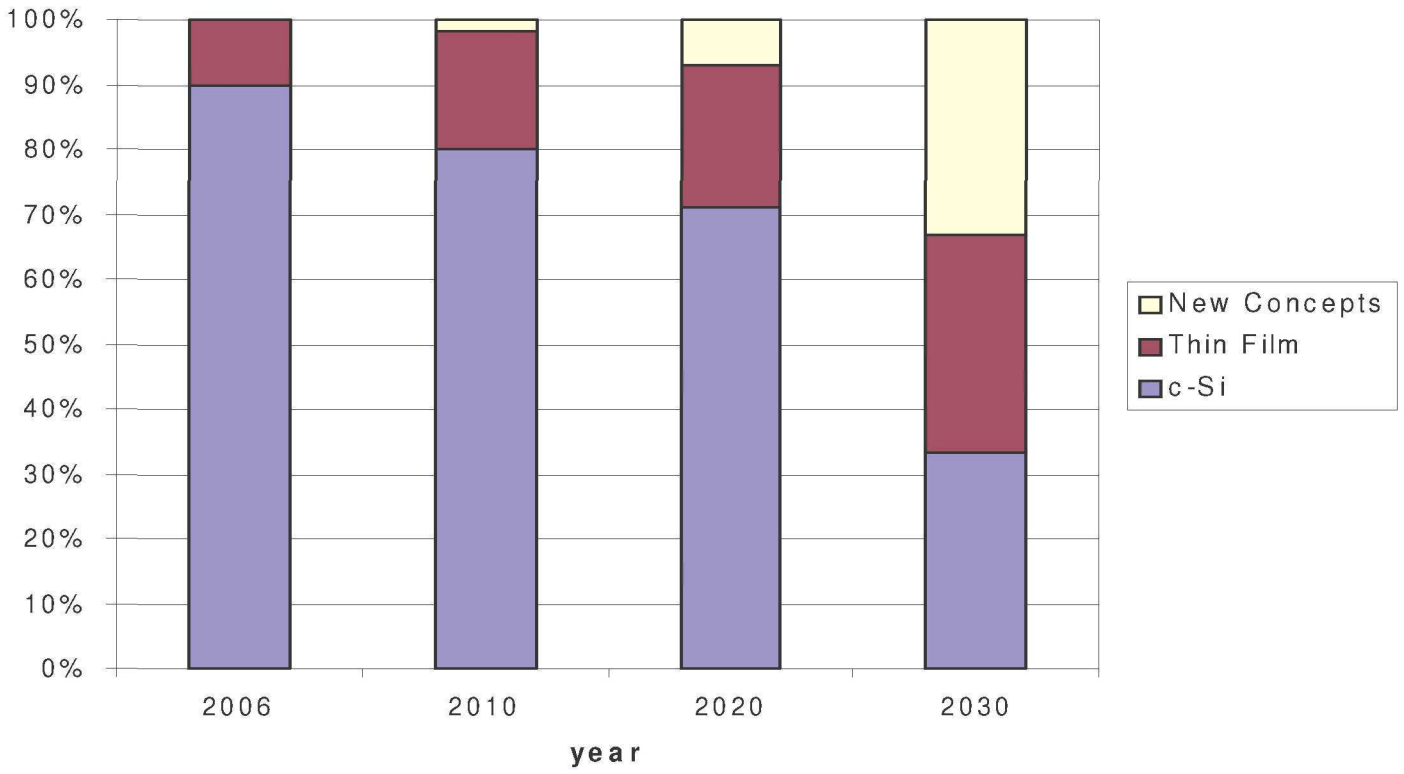
- allowed faster reduction of silicon specific consumption
- induced faster progress in automation
- opened a window of opportunities for other technolgies:

• Thin Films – ALL
• Concentrators
• Organic



Many initiatives under way. Thin film production may be as high as 1 GW in 2010

Technology mix in time – evolutionary scenario



Conclusions - 1

Progress in silicon wafer-based technology with time has determined the price-learning curve of PV modules that shows a decrease of about 20% for each doubling of capacity.
This progress has two driving forces: market size and technological improvement.
This did not happen by chance but is the result of the combination of market assisting measures and research, development and demonstration activities with both private and public support.

Crystalline silicon based technology has the capability to continue following the established price experience curve, with direct production costs expected to achieve significant reduction to around 1.00 €/W in 2013 and 0,75 €/W in 2020 and even lower in the long term.

This will happen if R&D effort is directed to address the most critical issues and the technology areas most likely to allow a continued progress of PV towards full sustainability.

Conclusions - 2

In the long term, it is expected that silicon technology will still play an important role in the PV sector, although there is uncertainty regarding the precise module efficiency, the silicon consumption, the cell and module architecture and component materials after 2020, when the market size is expected to be around 30 GW/year.

It is likely that silicon technology by this time will have incorporated aspects which are now related to novel or emerging technologies, and that new materials will also be included in the processing sequences.

In the long run, true distinctions between wafer and thin film technologies and between cells and modules may no longer be appropriate.

In the long term, it is expected that module efficiency will exceed the current laboratory record.
This may only be possible by incorporating technologies at the periphery of the device such as up or down converters. For this reason, basic and applied research on advanced concepts and materials should be included in crystalline silicon projects.

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www.eupvplatform.org

Thank you!