TRENDS IN PHOTOVOLTAICS RESEARCH, MARKET & TECHNOLOGY

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Overview

1. Basic motivation
2. Trends in Market
3. Trends in Technology
4. Trends in Industry
5. Trends in R&D
6. Summary

Basic motivation Renewable Energy

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- Depletion of the fossil and nuclear energy resources combined with a strongly growing energy demand (growth of global population, enhanced energy consumption per inhabitant)

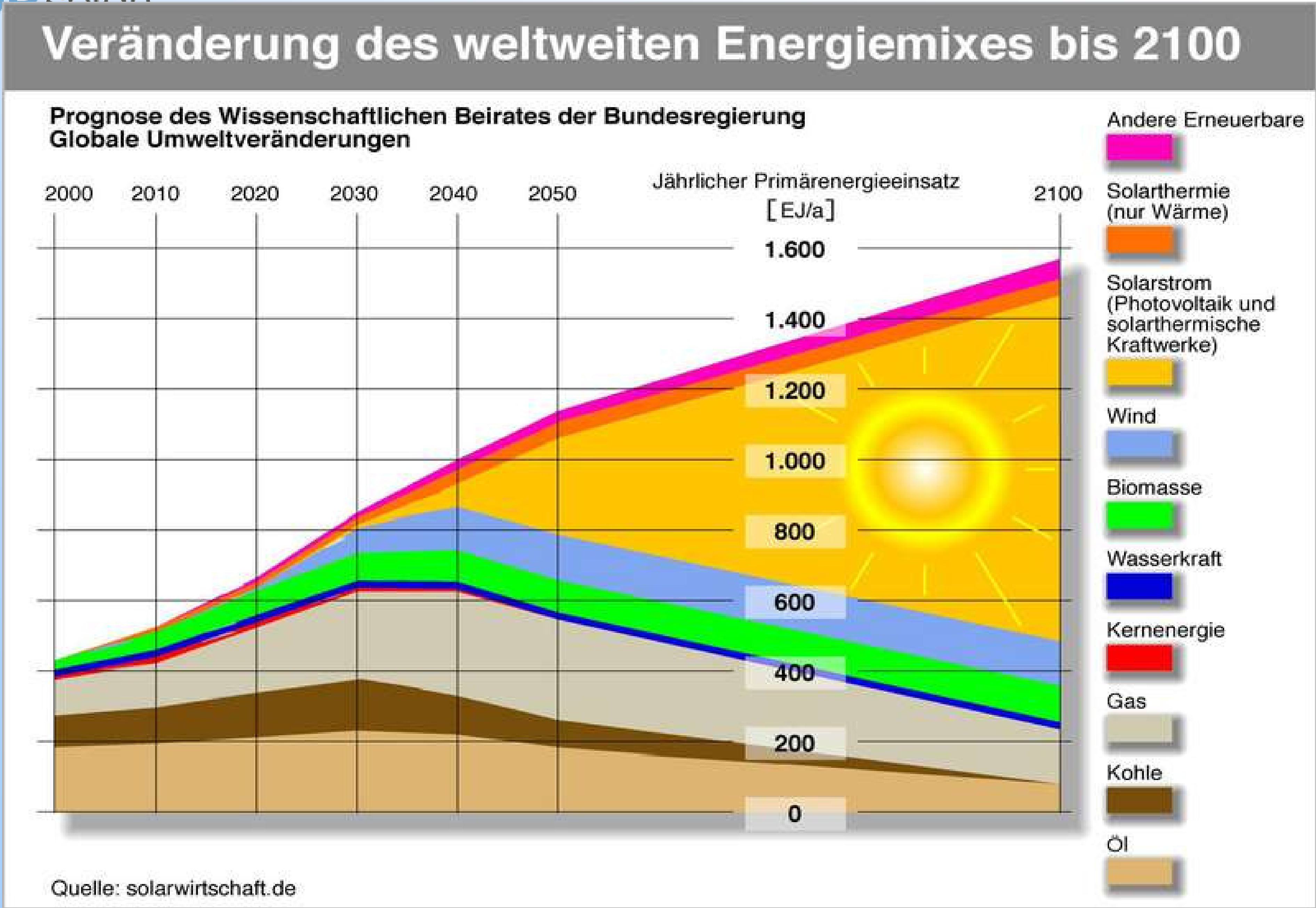
- Environmental friendly energy source (no air pollution and green house effect)

- Unlimited energy source (10.000x more solar irradiation than global energy consumption

- Strongly growing industry (CAGR: 30 to 40%)

- Consequences: strongly growing energy market with overpropotional increase in the share of renewable energies

Basic motivation Renewable Energy



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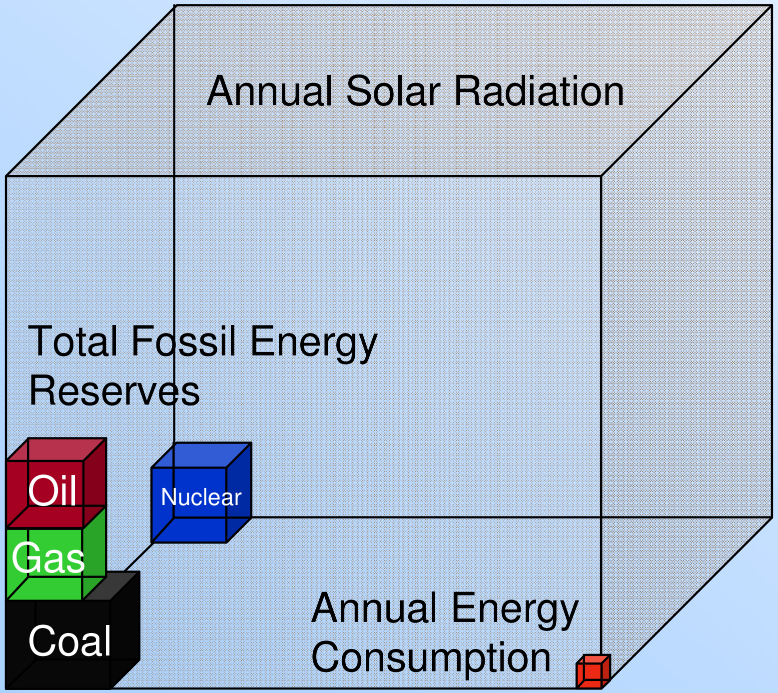
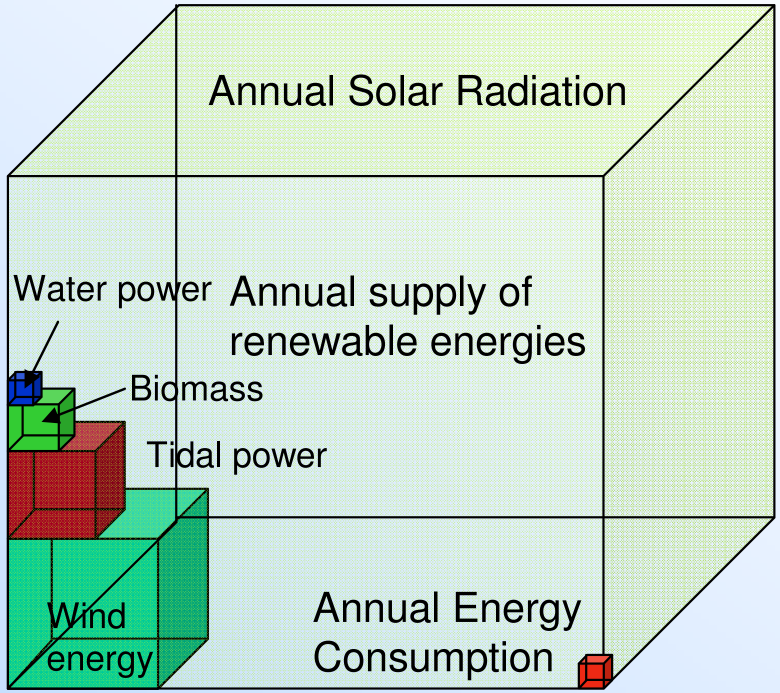
World energy consumption

Traditional energy sources



Renewable energy sources



Source: SolMic, Germany

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Basic definition

Photovoltaic Energy Generation is based on the principle of the direct conversion of Sunlight into Electrical Energy without the usage of additional conversion tools such as turbines

Applications

Applications

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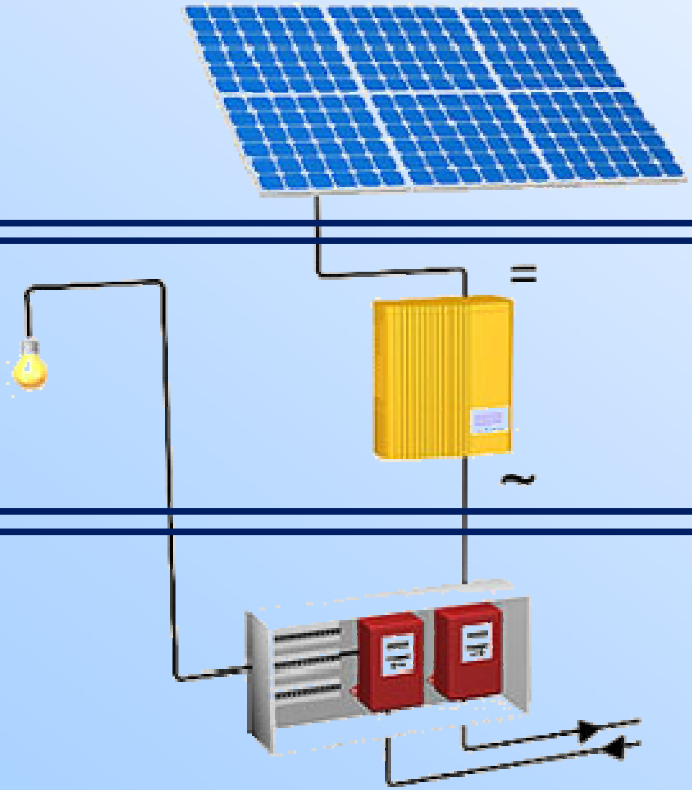
Basic Function of a PV-Grid-System



- DC-Electricity generated by Solar Panels
- Transformation in AC Voltage by an Inverter. The PV power can be used now within the house grid.
- An additional electric meter and the house connection allows the PV power to attain the Public Grid.

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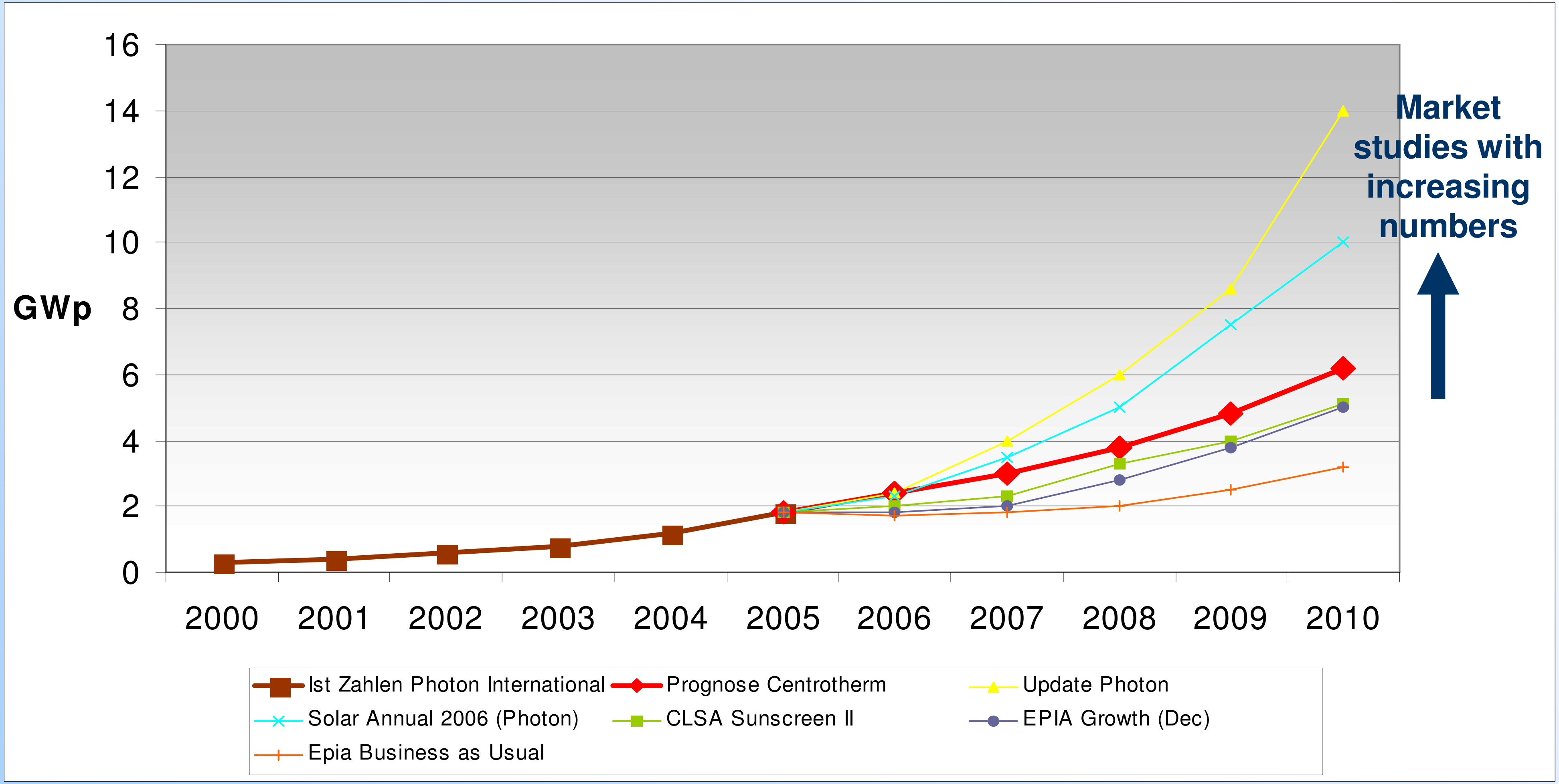
Trends in Market

PV Big Business

The PV Market



World wide PV Market 1.8 GWp in 2006 and 6 to 8 GWp (own expectation) in 2010 (CAGR: 25 to 35%).

World wide Turnover of the Crys. Si PV industry (PV Modules) €4.8 bn. in 2005 and est. ca. € 20 bn. in 2010.

Subsidies for Photovoltaics in different countries

Germany

- FIT in 2004 started
- FIT 20 years with an annual decrease of 5%
- strong political support

Spain

- New PIT in March 2004
- FIT 25 years; Upper limit 400 MWp

Italy

- „Backwards running electrical power Meter >20 kWp
- „Programma nez. tetti fotovoltaici“ Investment subsidies up to 85%

France

- FIT Private sector over 20 Years 0,15 €/kWh < 12MW, Increase to 22,5 €/kWh planned.
- Reduced VAT for PV investments

Japan

Ending subsidy program for roof top integrated PV in 3/2006, but new goal (4,82 GWp) till 2010

China

Rapidely growing energy consumption covered also by PV
Goal: 450 MWp till 2010.
FIT starting from 2006. Goal: 10% of energy demand should be covered by PV

Rest of Asia

Subsidy program in Korea (1,3 GWp till 2011) and Thailand (300 MWp). India increasing interest in PV. New big integrated projects under discussion.

USA

- Subsidy program in California: „1 Million roof program“ till 2016, budget 3,2 Bio. US$
- In 30 states discussion of FIT programs

Source: Mr. Bösl, Munich, Germany

Trends in Technology

Which is the right PV
Material?

Crys. Si. Photovoltaic market outline to 2010

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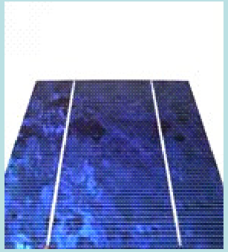
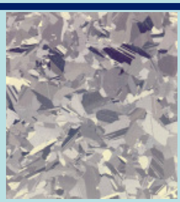


	2005	Projection 2010e
Solar Modules	1.5 GWp	7 GWp
	€4.8 bn	€ 20bn
Solar Cells	€3.1 bn	€13.3 bn
Solar Silicon Wafers	€1.6 bn	€6.8 bn
Solar Grade Poly Silicon	€0.8 bn	€3.7 bn
Total	€10 bn	€45 bn

Cost distribution

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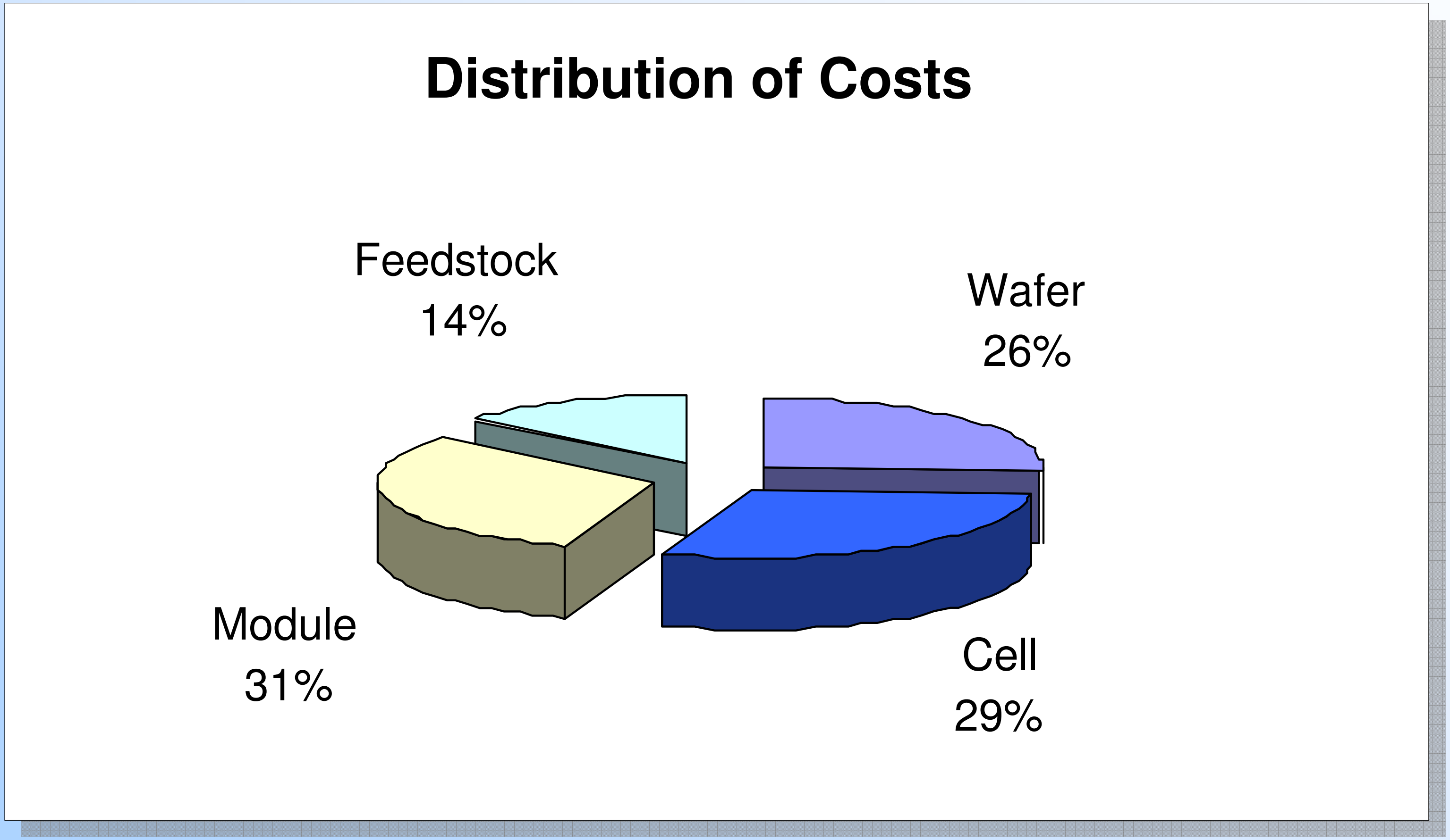
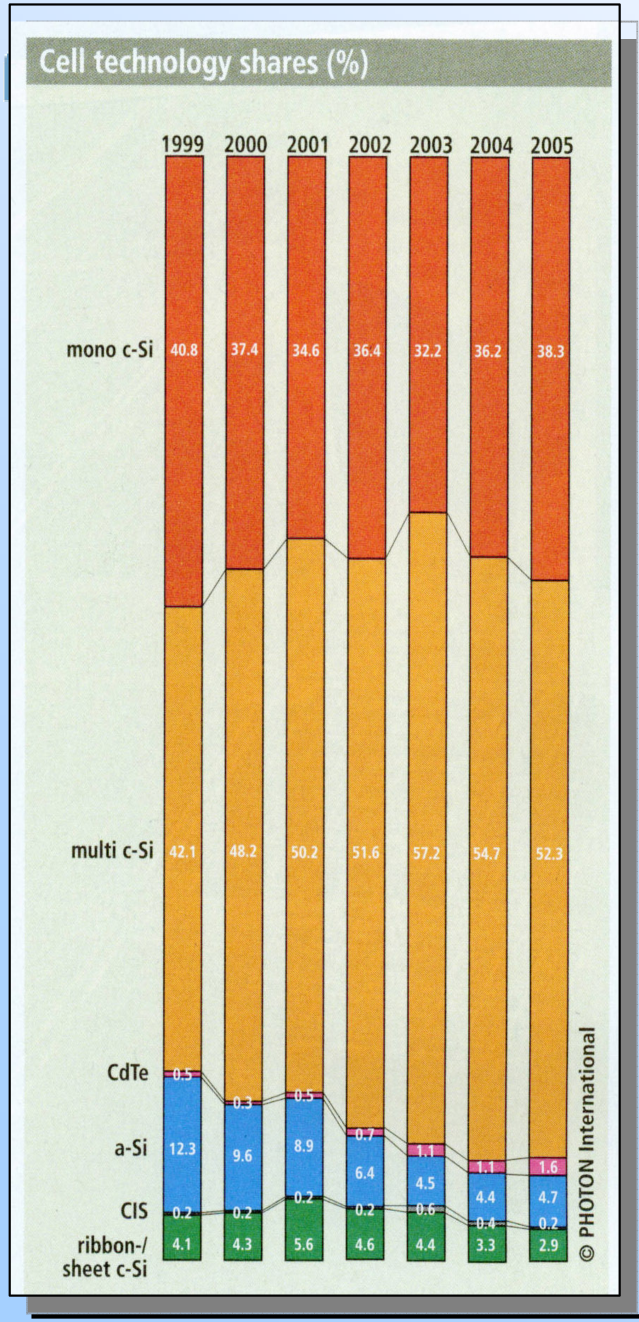


Manufacturing cost of a cry. Si module (Europe): 1.4-1.6 Euro / Wp
Assuming no profit and company overhead over the whole value chain

Source: GP Solar Konstanz / SolMic Burghausen

Photovoltaic Materials

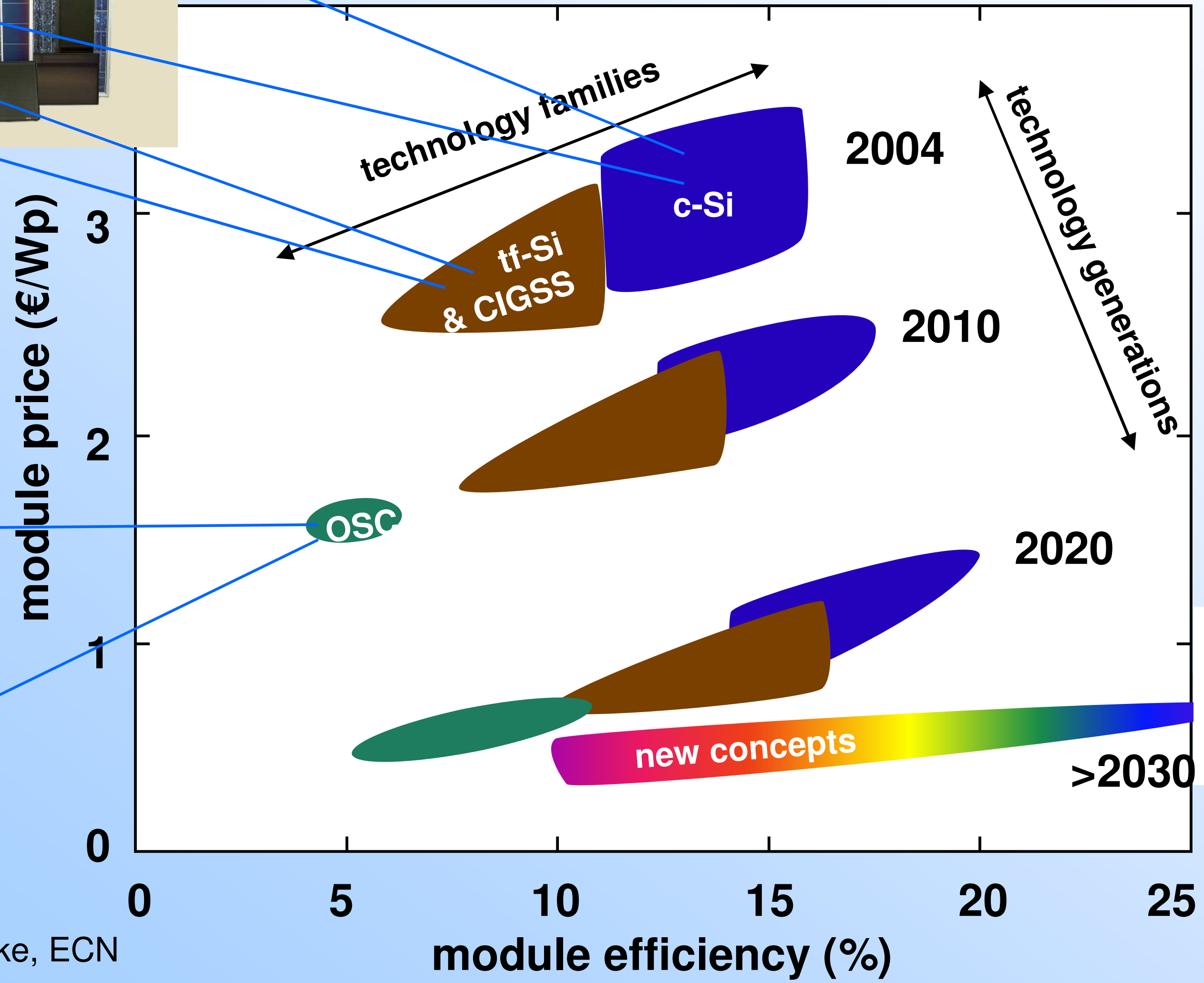


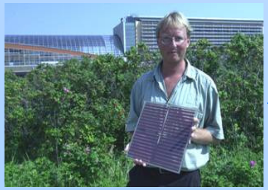
- The PV Industry is based on Silicon (2005: 97.2%)
  - silicon is the most widely spread semiconductor material on earth (25.8% earth crust) profiting in its PV application from its usage in electronic industry (microelectronics and optics)
- The crystalline silicon has a share of 92.5% abs. (2005)
  - Longest experience in PV industry with crys. Silicon, high efficiency potential, benefiting from µE industry
- Multi crystalline Si dominates with 52.3% followed by mono Si with 38.3% and ribbon Si 2.9%
  - Multi crys. Si wafer manufacturing easy to be scaled up, lowest cost potential
- Thin film reduced contribution from 13% in 1999 to 6.5% in 2005
  - Low efficiencies combined with higher manufacturing cost per Wp on system level, new manufacturing technology/equipment required, reduced customer acceptance (CdTe, CIS), high initial invest per MWp module (whole value chain: from semiconductor material to finished module), availability of components (Te, In) of compound semiconductors material, delayed factory projects

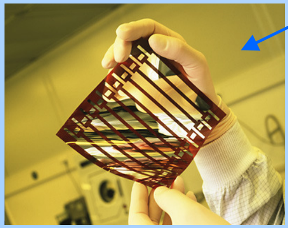
❖ Our focus in this lecture will be the Crystalline Silicon Photovoltaic value chain

Source: Photon International, March 2006

Expected results and impact: 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)

Source: W. Sinke, ECN

Introduction Thin Film

- Potential alternative to Crystalline Silicon Wafer based technology to manufacture PV modules
- Basic idea: the deposition of a thin film of a semiconductor material as PV active layer on glass
- Applied materials:
  - Silicon based thin film:
    - Amorphous, microcrystalline, poly crystalline Silicon, amorphous SiGe,
  - Compound semiconductors:
    - Copperindiumdiselenid (CIS), $CuGaInSe_2$ (CIGS), $CuInS_2$, Cadmiumtelluride (CdTe), TiO2 (dye sensitized solar cells),
  - Organic semiconductors:
    - Polymers, …
- Industrialization:
  - Most advanced: amorphous Si, CiS, CdTe
  - No prominent Thin Film Module manufacturer under the Top Ten
  - Typical annual production volume (between 1MW and max. 20MW)

Performance of Thin Film Technology

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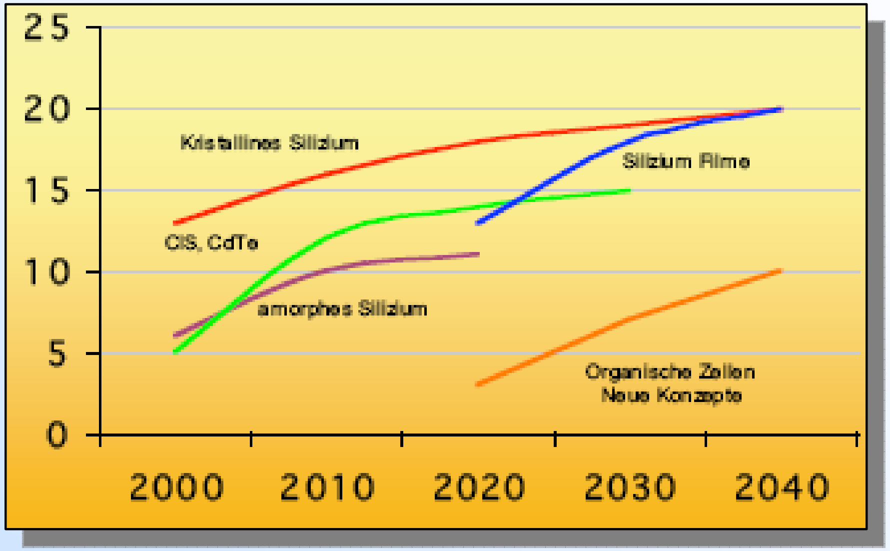
Material	Module efficiency [%]	Best Lab. efficiency [%]
Crystalline Silicon		
Cz Si (PV grade)	14-17	22.0
Multi Si	12-14.5	20.4
Ribbon Si	12-14	17.8
Thin Film Silicon		
Poly Si film	9.3	12
Amorphous Si	4-7	12.7
Compound thin film		
CdTe	8-10	16.1
CIGS	8-12	19.1

Source: Own research, Prof. Dr. Möller Freiberg 2005

Efficiency perspective of PV Materials



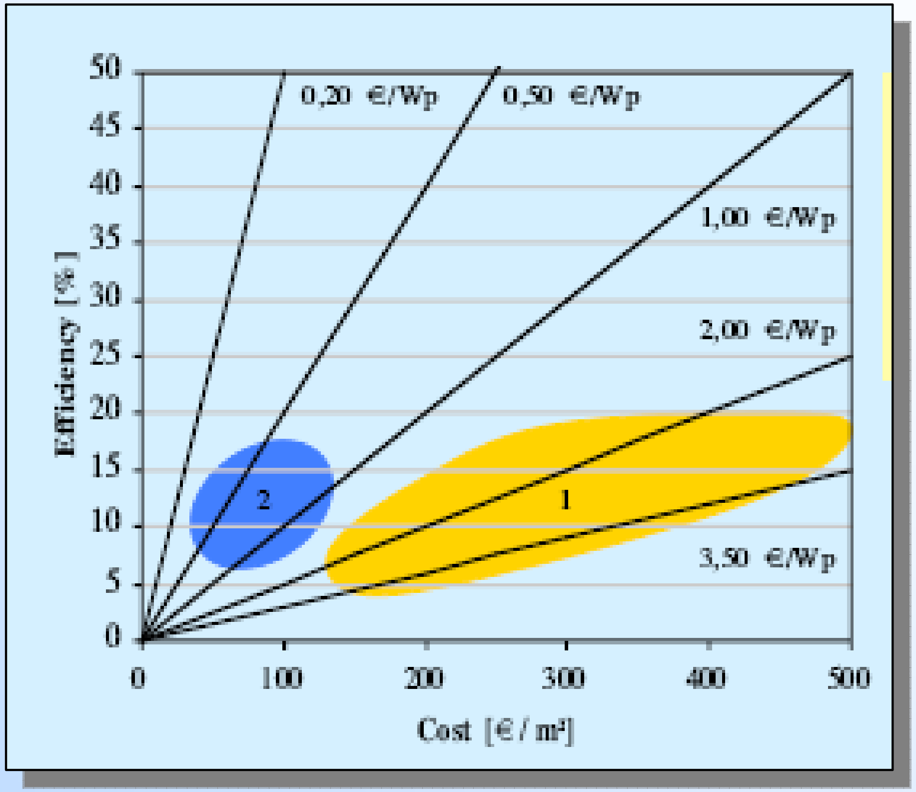
Source: Prof. Dr. Möller Freiberg 2005

Chances and risks

Chances and risks

- \+ Potential revival of thin film PV technology due to poly Si shortage
- \+ Cost reduction potential
- \- Mass production not yet reached
- \- Low efficiencies especially for amorphous Si technology
- \- Low manufacturing cost per m2 needed to enable low cost per Wp (today: 2 – 2.2 €/Wp) in PV system
- \- For compound semiconductors:
    - \- CIGS/CIS: limited availability of Indium (competition to flat panel display industry)
    - \- Low customer acceptance due to the usage of toxic materials (Se, Te, Cd)
    - \- No synergetic effects with mainstream electronic industry

PV Systems cost in dependence on the module efficiency and module manufacturing cost per m^2



Source: Study M. A. Green 2002, EU APAS 1997

Thin Film PV module manufacturers

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Company	Technology	Status
Kaneka Jp	Amorphous Si	Production 20 MWp
Sharp Jp	amorphous / crystalline Si	Production 15?MWp
United Solar USA	Triple Junction (a-Si; SiGe)	Production 14 MWp
Mitsubishi Jp	Amorphous Si	Production 10 MWp
Canon Jp	Triple Junction (a-Si; SiGe	Production 10MWp
First Solar USA	CdTe	Production 6 MWp
Antec D	CdTe	Production 7MWp
Schott Solar D	Amorphous Si	Pilot / Mass production: ?MWp
Würth Solar D	CIGS	Pilot production 1.3 MWp
Shell Solar (Showa/Shell) Jp / USA	CIS	Pilot production 1,2MWp
Sulphurcell D	$CuInS_2$	Pilot line
Unaxis / sunways CH/D	Amorphous / micorcrystalline Si	Lab scale (Unaxis: equipment supplier, Sunways: manufacturer)
CSG D/AUS	Poly crystalline Si	Setting up of factory

Source: Own research, A. Jäger Waldau: JRC PV Status report 2005

Thin film: Intermediate conclusion

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- Amorphous / microcrystalline silicon technology most suitable for mass production of thin film PV modules

- Thin film technology amorphous (later a Si / µc Si) could be integral part of the PV roadmap as future option

- Compound semiconductor thin film technology high technology risk, customer acceptance and sustainability questionable

Development of the solar cell production

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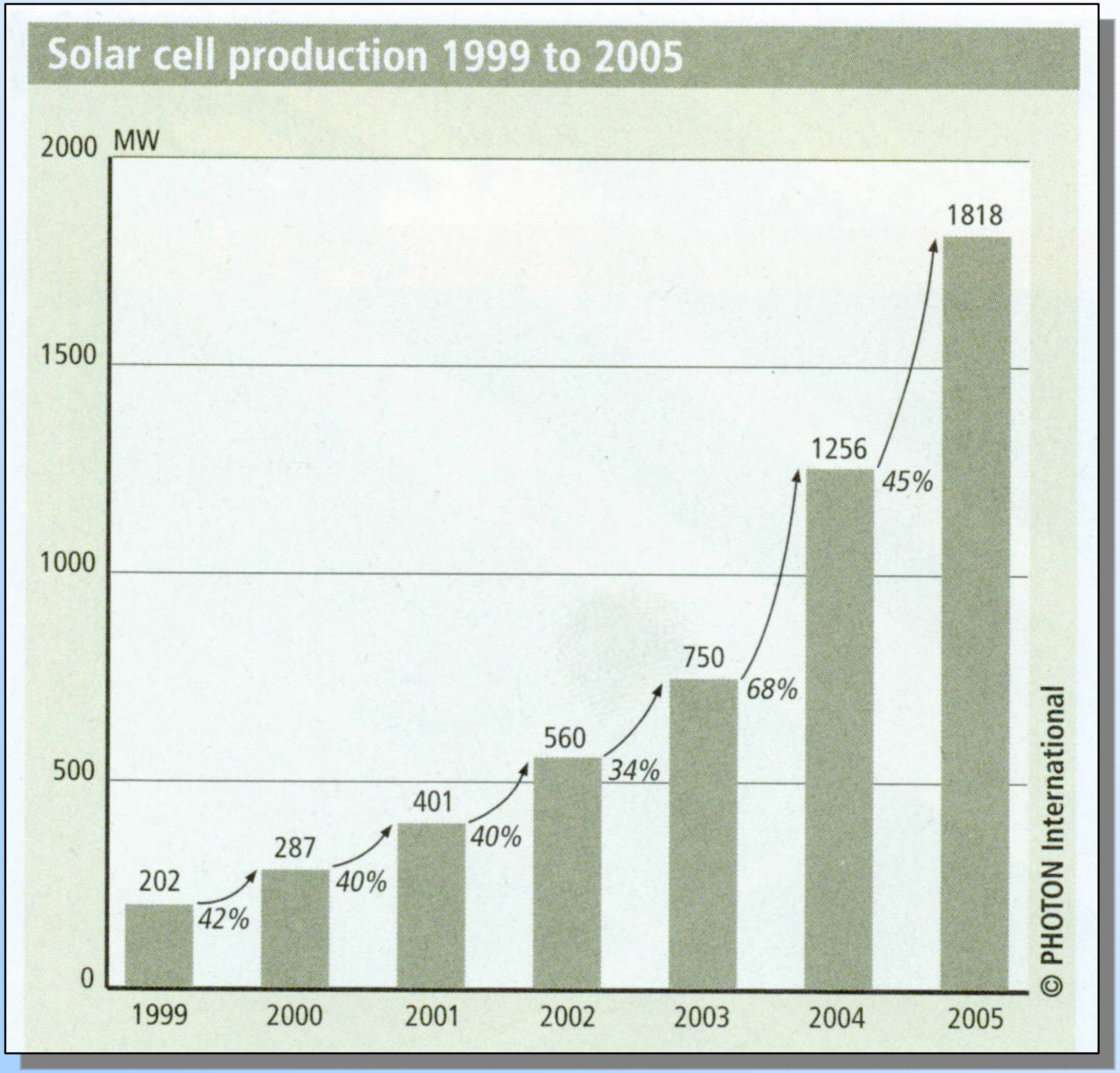
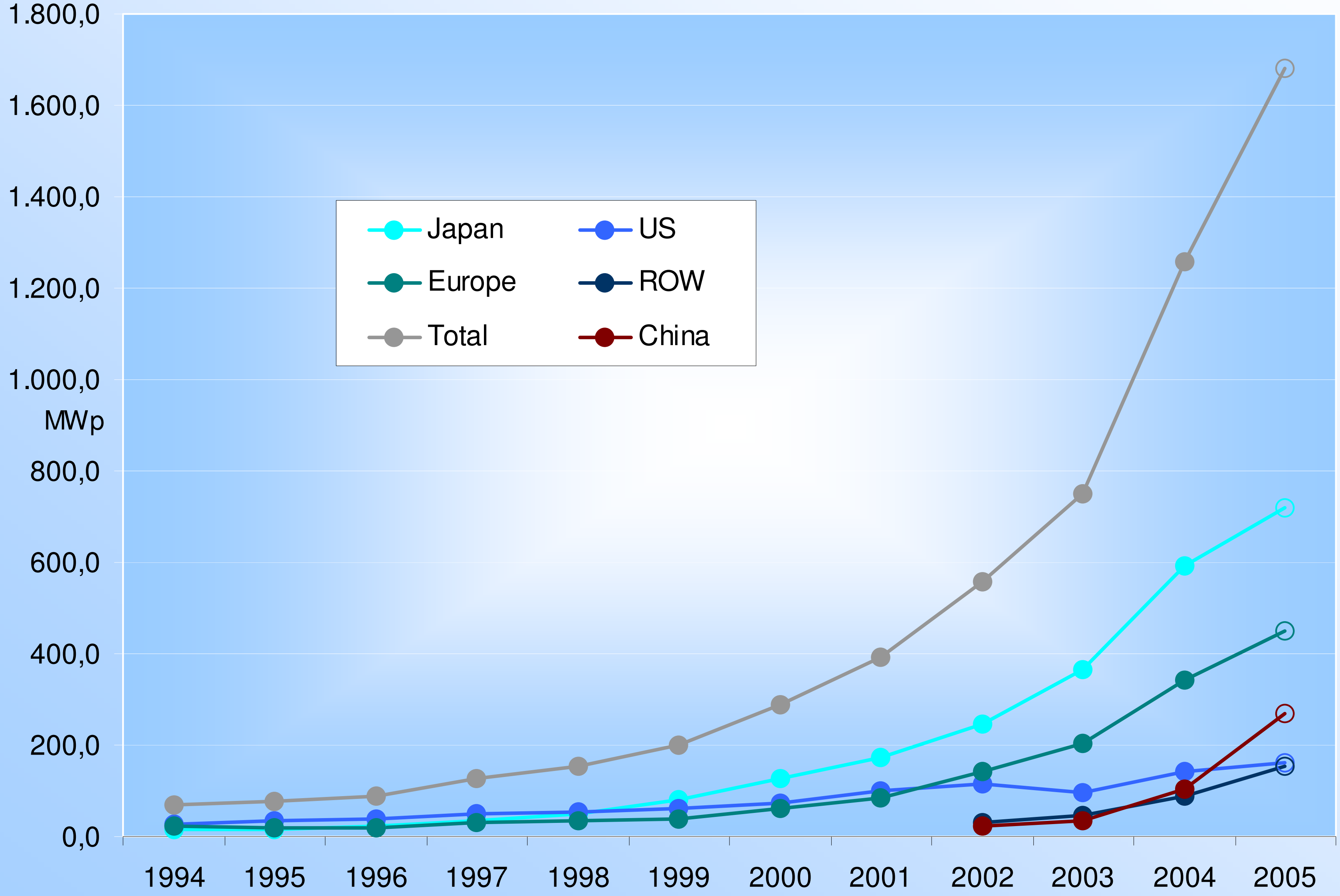
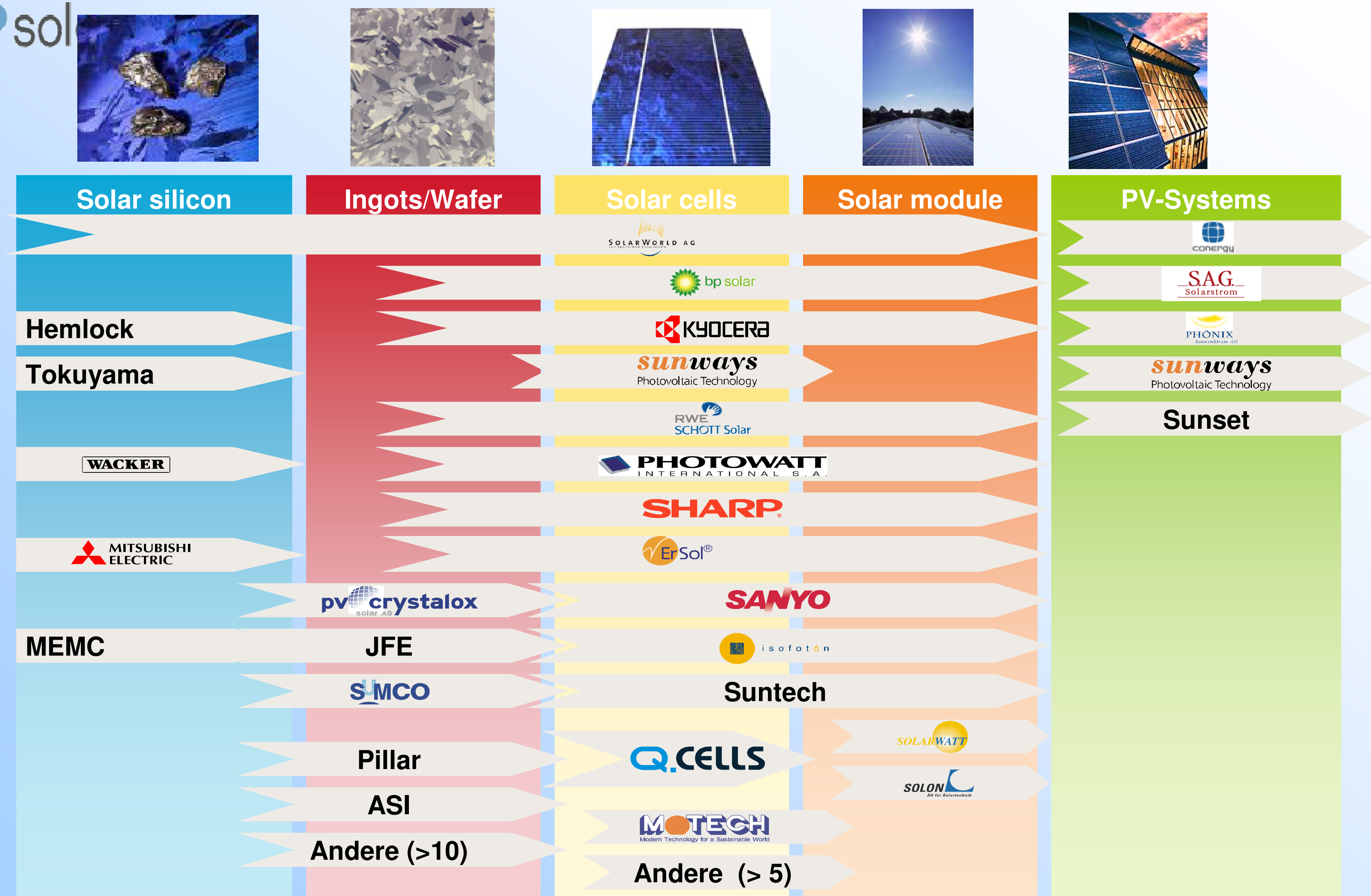


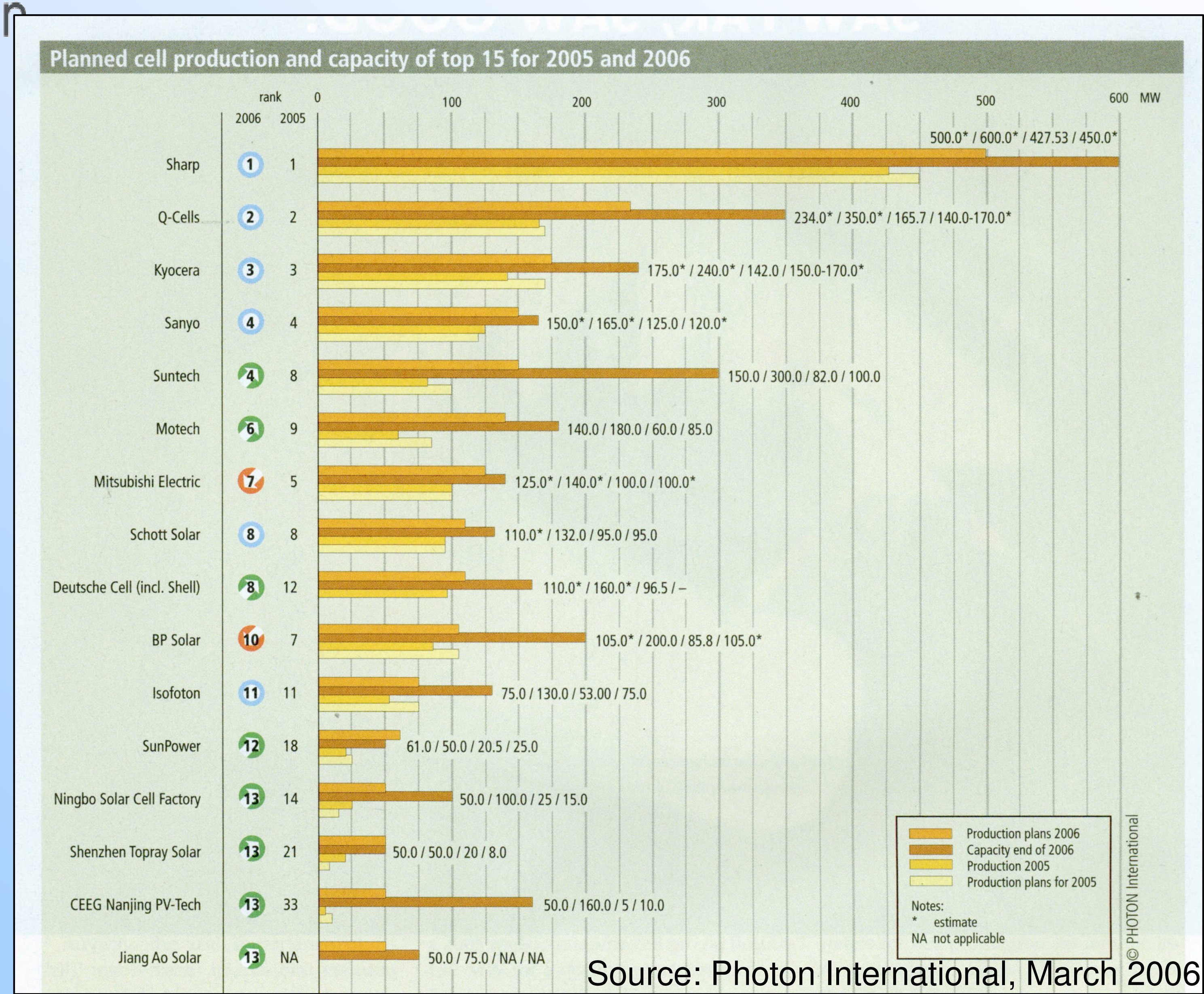
Worldwide producers





Consolidation, forward and backward integration: in future fully integrated production

Capacity increase



Source: Photon International, March 2006

Expected results and impact (3): evolution of turn-key system prices

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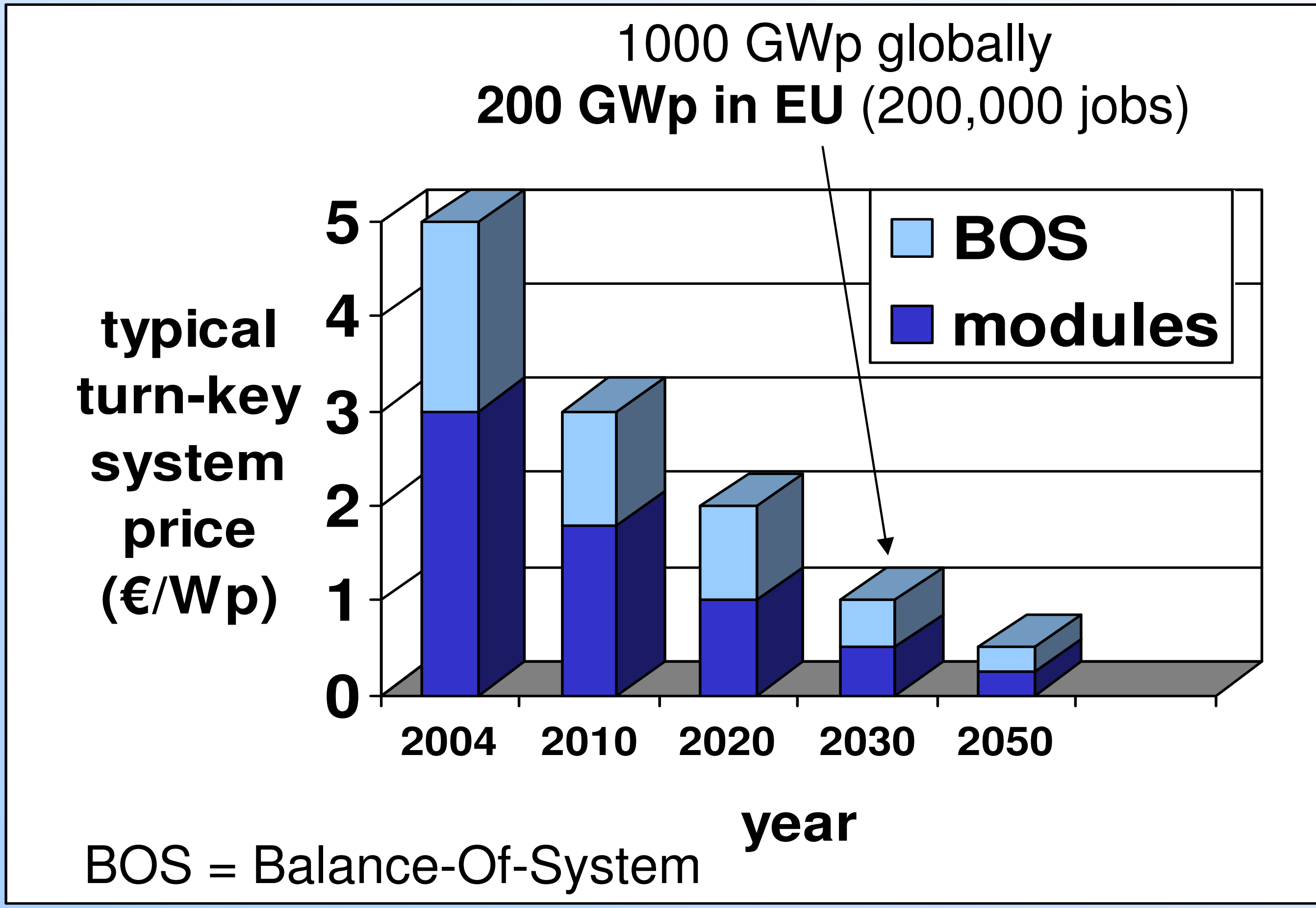

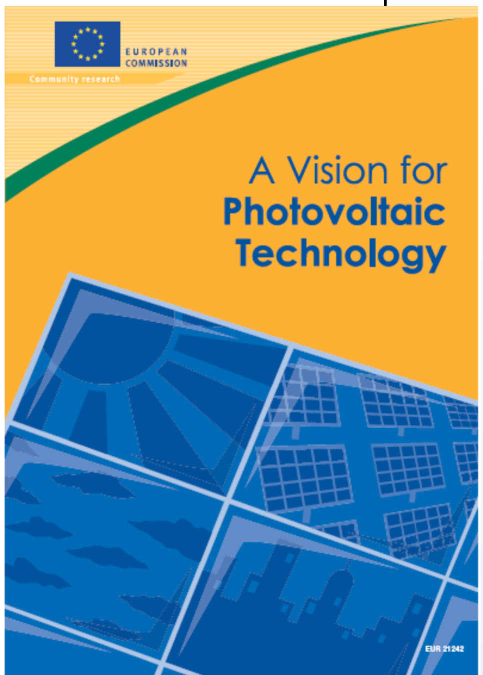

http://europa.eu.int/comm/research/energy/pdf/vision-report-final.pdf

Trends of price per KWh in electrical power generation

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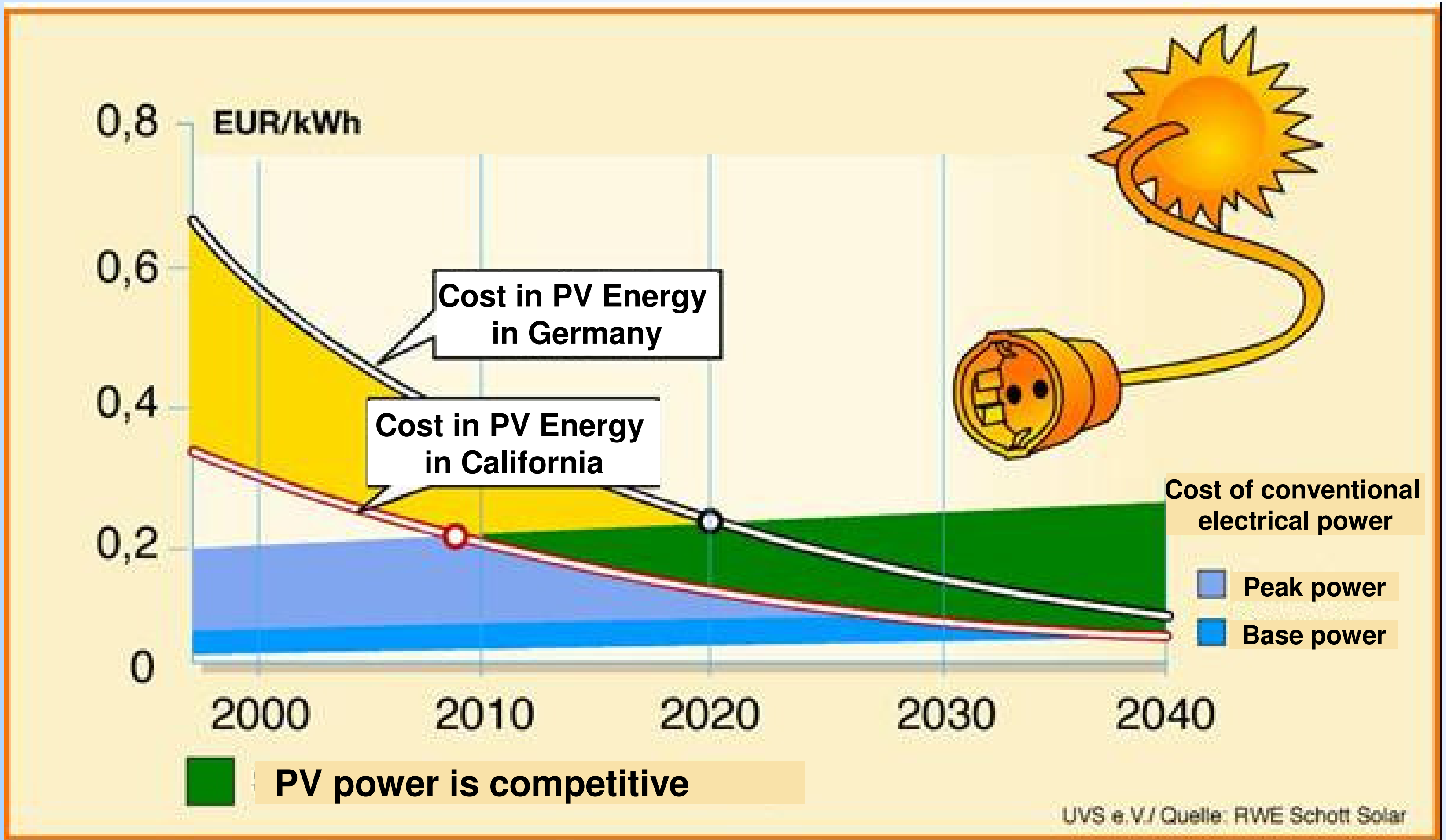
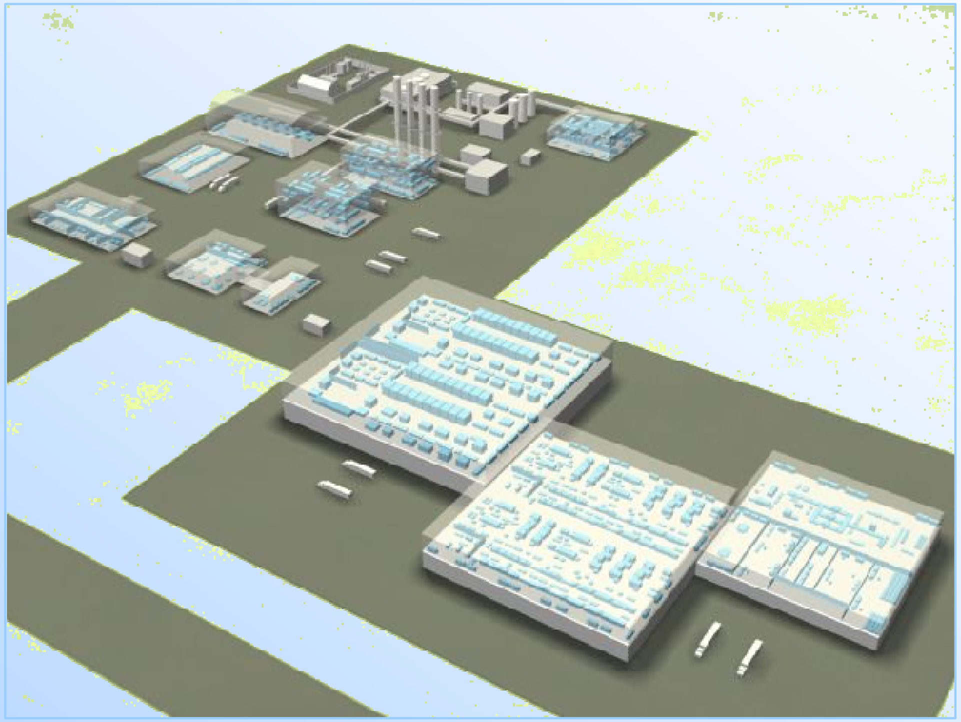


The price for PV power is decreasing continuously whereas the price for conventional electrical energy is increasing

It is expected that within this decade solar power generation will be competitive in selecected countries.

Trends in Industry

Fully integrated
1 GWp Solar Factory



Basic motivation

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- In past year ongoing discussions in crystalline silicon photovoltaic:
  - Integrated fabrication throughout full value chain contra
  - Separated specialized companies (poly Si, wafer, cell, module) for each segment of the value chain

- Highlights integrated fabrication:
  - Reduced cost due to enhanced overall product yield due to omission of long distance shipment of wafers and cells
  - Fast feedback loops and significant optimization potential over the entire value chain results in better product quality and yield
  - Reduced investment cost
  - Simplified up scaling of production through ownership of manufacturing know how of all segments of the value chain

The integrated Solar Factory Design (250MWp)

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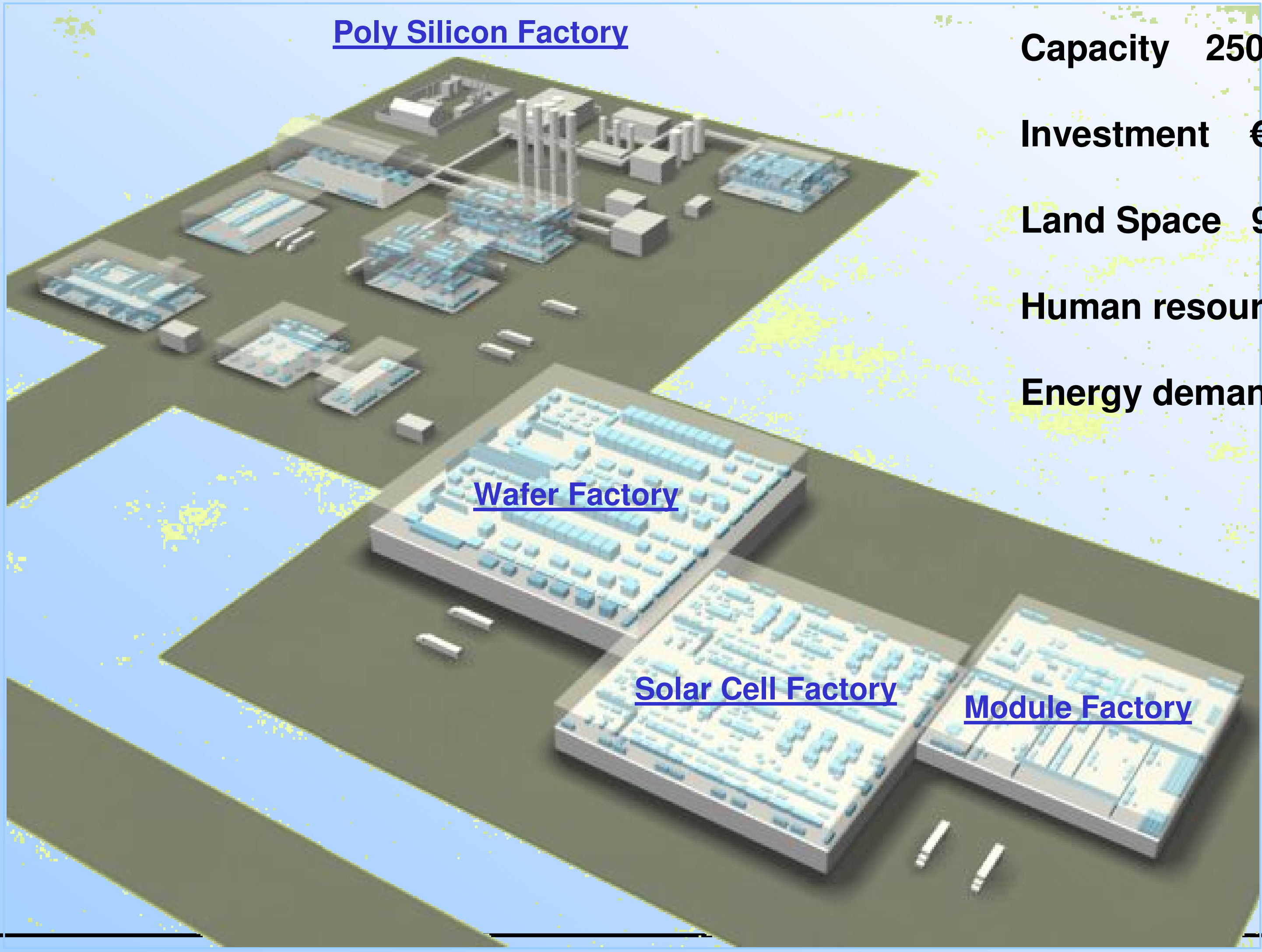
Standard fully integrated batch type factory (250MW subunit)



Capacity 250 MWp/a

Investment € 550 million

Land Space 90000 m²

Human resource 2100 employees

Energy demand 95 MW

Cost break down

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Cost calculation for a 1 GWp/a Solar Cluster		
	€/Wp	
Poly Silicon plant including TCS production	0,28	28%
Ingot facility	0,18	18%
Wafer Fabrication	0,08	8%
Cell Fabrication	0,24	25%
Module Fabrication	0,20	20%
Total Costs	0,98	

Summary

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- Fully integrated 1GWp factory design analyzed:

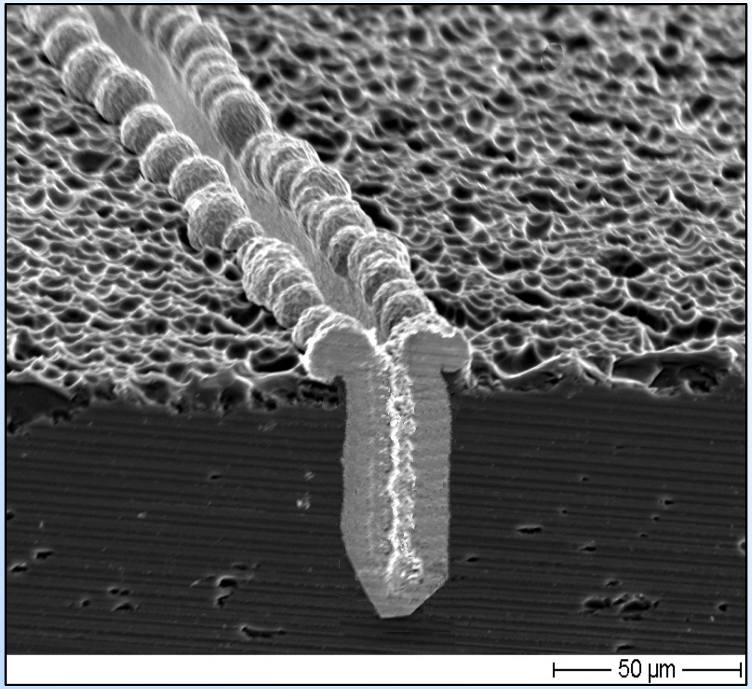
Key message:

1 GWp fully integrated factory beneficial (cost reduction) and feasible

but needs time

Trends in R&D

Crystalline Silicon:
Thinner
Bigger
Better



Source: M. McCann, Universität Konstanz

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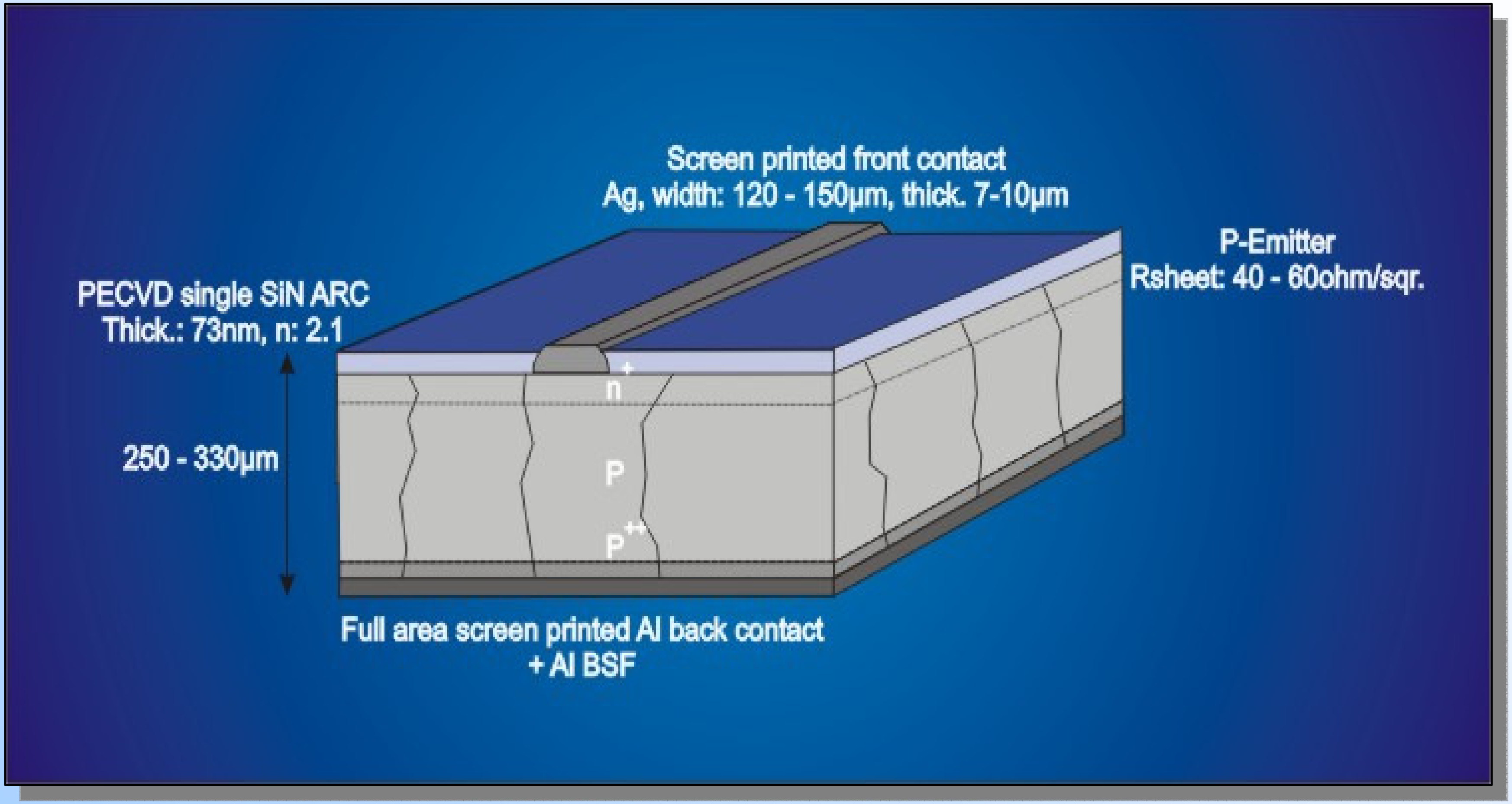
Status: Device structure

Typical industrial Si solar cell



Device structure of nearly 100% of all multi Si and 75% of all mono Si solar cells

Typical efficiency: multi av. 14.8 ↔ 15.3% mono av. 16.2 ↔17%

Status: Manufacturing process

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- **Efficiency:**
  - Average
  - Multi 14.5 ↔ 15.5%
  - Mono 14.5 ↔ 20%
- **Yield:**
  - Mechanical/electrical loss
  - (high material quality 270µm):
    - 3 to 5%
  - optical loss: 2 to 3%
- **Throughput:**
  - 750 - 2400 pieces/hour
- **Capacity per line:**
  - $12.5x12.5cm^2$ 28MW/a
  - $15.6x15.6cm^2$ 50MW/a

Technology trends

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- Material shortage:
  - Development of own poly Si supply
  - More emphasis on yield and efficiency enhancement
  - Device and manufacturing technology for thin wafers (below 200µm)
  - More resources focused towards thin film technology

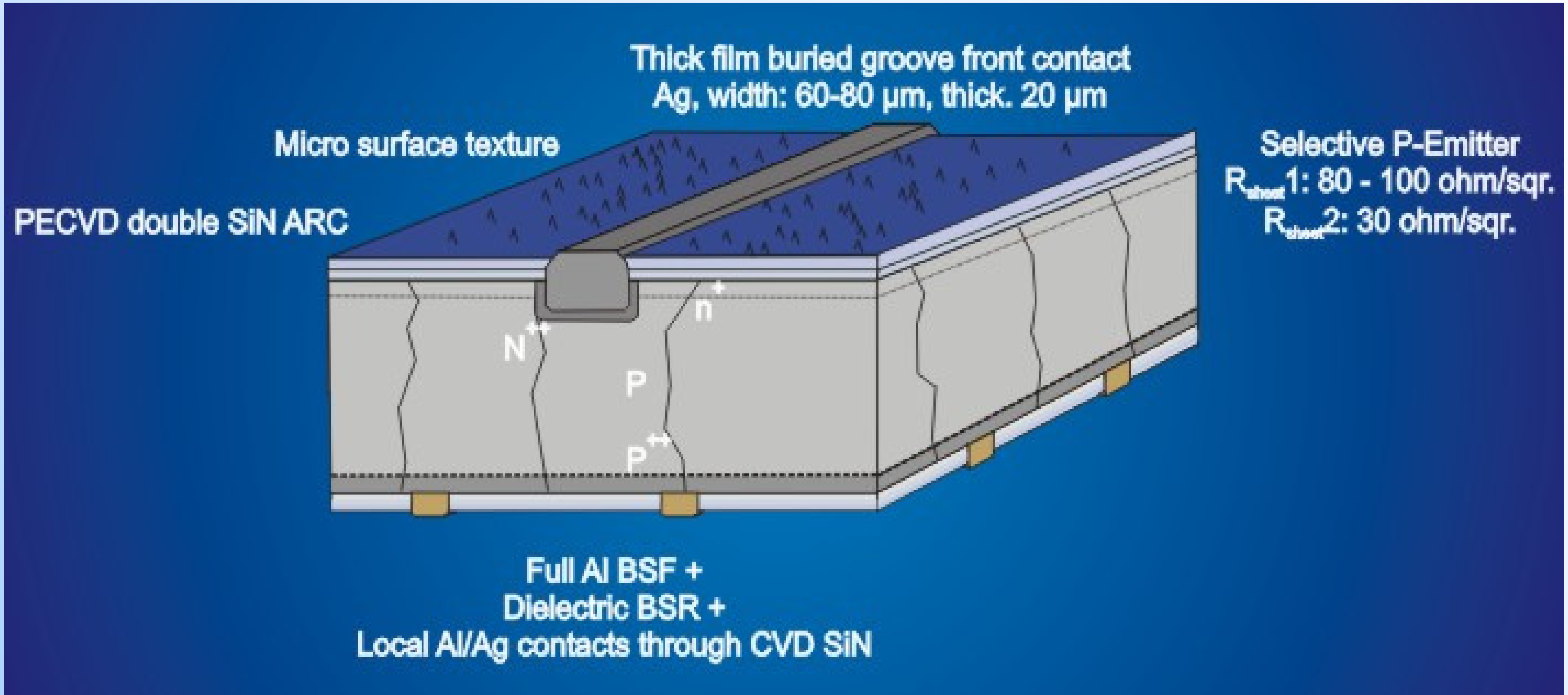
- General trend of fully integrated companies (from feedstock to module)

- High throughput production (first factories with 3000 wafers per hour and line)

- Next generation of new inline production technique currently under development at leading equipment manufacturer

Perspectives: Device structure

Future (3 years) industrial multi Si solar cell



Manufacturing process

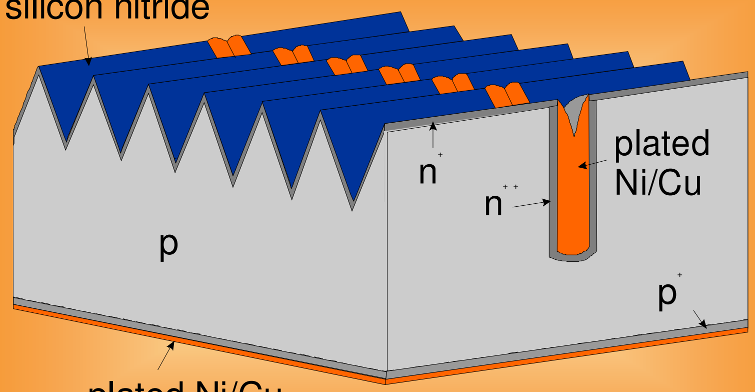
- ISO-Texturing
- Thick-Film Buried Contact Metallization
- Double Anti-Reflection Coating
- Full Area Rear Side
- Optional Aspect:
- Full BSF additional to dielectric coating & local back contacts

- **Efficiency potential: 17%**

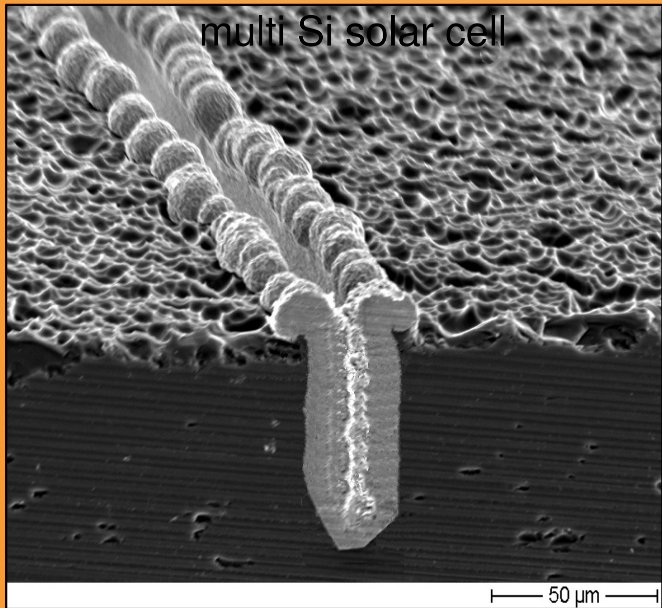
- Manufacturing technology
- Inline processing required (large area >15x15cm² and reduced thickness 200 – 230µm)

Perspectives: High efficiency multi Si

Multicrystalline Si Buried-contact cells



Isotropically (acid) textured BC multi Si solar cell



IV Measurement

Solar cell size: 12,5x12,5 cm²

texture	V_{oc} [mV]	J_{sc} [mA/cm²]	FF [%]	η [%]
alkaline	602	32.1	77.4	15.0
V-textured	636	36.9	77.0	18.1*

* POLIX wafer; independently confirmed by FhG-ISE, Freiburg, Germany

Source: M. McCann, Universität Konstanz

Overall Summary

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No revolutions only evolutions in crystalline silicon solar cell technology

☺ Bright future for crys. Si

- Cost potential 1Euro / Wp of finished modules
- Established technology
- Big fun: hunting for higher efficiencies, yield, throughput
- A lot of opportunities for mechanical, electrical, chemical engineers as well as material scientists, chemists, physicists in R&D, technology transfer, industrialisation

Opportunities in South Africa

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- Excellent place for an integrated crystalline silicon solar fabrication
- Critical mass for an vivid research cluster in crystalline silicon Photovoltaics
- Starting your own crystalline silicon industry in SA
  - Example Ilangapower

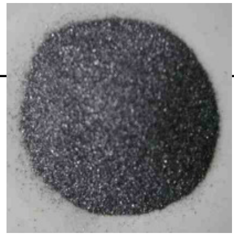
ilangaPower
Solar Cell Manufacturing in South Africa

October 2007

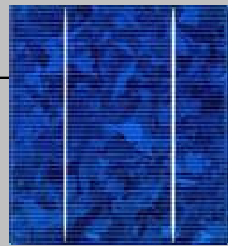
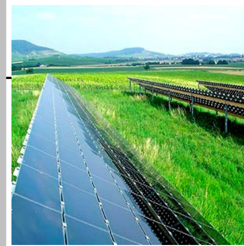
The process from quartz to the solar cell module

ilangaPower

SiO$_2$ / MG silicon	Solar-grade Poly-Si	cast block / wafers	Solar cell	Module
Sand to metallurgical silicon	MG Si to pure Si	silicon to solar wafers	wafer to solar cell	cell to module
Silicon Smelters, SA	Hemlock, USA	Swiss Wafers, CH PV Wafer SA	QCells, D 340MW/a	Tenesa, SA

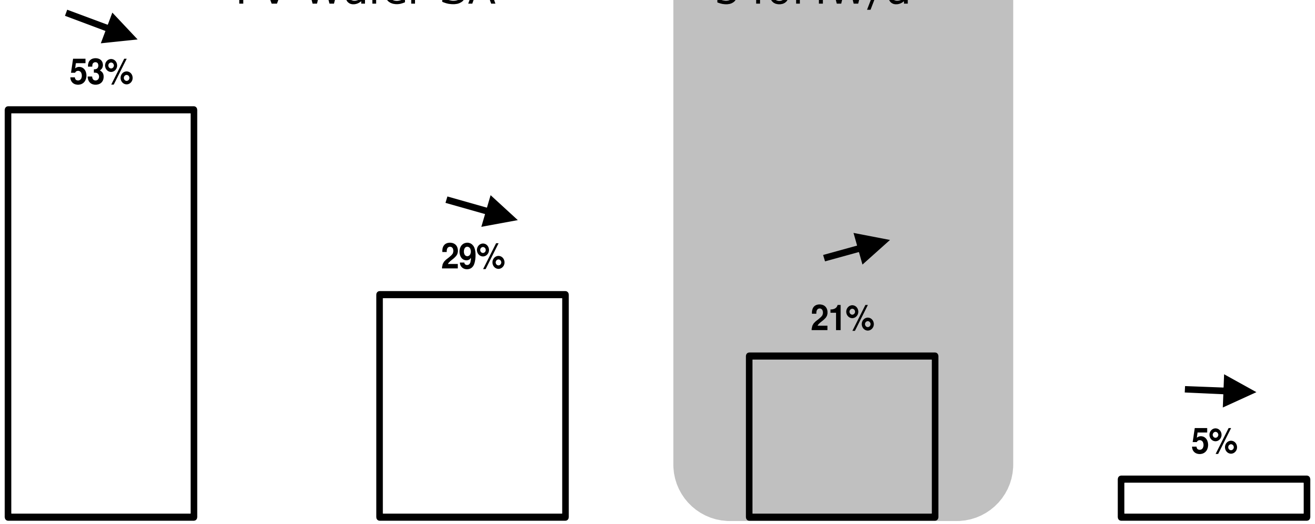





EBIT margin for cell production will be good and stable

- High margins for silicon and wafers due to temporary shortage
- Margin for cells is likely to rise due to technological challenges
- Invest for wafers twice, for Si 10 times more than for cells



EBIT margins for the PV value chain (Rogol 2006)

The ilangaPower project

Summary

- Investments in Photovoltaics technology promise **long-term and solid profits**
- Solar cell technology is the driver in the race for cost reduction and efficiency increase, thus **profit margins** for cell producers will remain **high**
- ilangaPower will produce **solar cells from poly-silicon** wafers using newest **proven technology**
- It will become a global **leader in cost reduction and efficiency increase**
- ilangaPower will be located in the **Western Cape**

About IlangaPower

- ilangaPower's strong points are: **secured silicon supply**, **strong management team**, newest **proven technology**, and a solid **technical roadmap**
- ilangaPower targets for a **global** trademark and a dominant position in the emerging African market
- The management is a team of renowned European and South African PV experts
- We seek broad support from parastatal South African as well as private equity investors

About our targets

- ilangaPower starts with 32MWatt/year capacity
- **EBIT margin** will reach 15% in H2 2009
- Capacity is increased to 65MWatt/year as soon as ilangaPower's objectives in quality, efficiency and volume are achieved (2010 – 2011)
- **EBIT margin** will reach **23%** in 2011
- ilangaPower needs **42MEuro cash in total**, 35MEuro to reach the 32MWatt/year stage
- We envision 50% contribution from shareholders/50% bank loan
- Scaling up to 1GWatt/year or **expanding the business** upstream to wafer/ingot/crystal/silicon are options

Location, Ramp-Up

- **South Africa** provides an **attractive cost model** and good infrastructure
- **Cape Town** is attractive for local and foreign **highly-qualified personnel**
- Seamless **co-operation** between ilangaPower and **European technology partners** can be implemented
- Cape Town hosts a significant customers base
- Cape Town is the pole position for dominance in the emerging **African market**
- **Ramp-up**, fine-tuning, and training will be under the responsibility of the European turnkey suppliers
- Close **co-operation** with South African **top universities**

Contacts

THANKS FOR YOUR ATTENTION

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