Photovoltaik: Marktpotential und technologische Trends am Beispiel kristalliner Siliziumtechnologie

11th Leibnitz Conference of Advanced Sience - May 13th 2011

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CONTENT

BUSINESS SEGMENTS
PRODUCT OFFERINGS

Solar Cells

multi

mono

Solar Modules

Q.Base/Q.Pro

Q.Smart

Q.Smart UF

Q.Smart UF L

- **Q.Smart**
  Intelligent aesthetics for a wide range of applications
- **Q.Pro**
  Raising the bar for highly reliable energy output
- **Q.Base**
  High performance for large-scale solar arrays

Solar Systems

TRANSFORMATION FROM A PURE CELL PLAYER TO A GLOBAL PROVIDER OF PV-SOLUTIONS

SOLAR VALLEY THALHEIM - HEADQUARTER

Q-CELLS AT A GLANCE
Q-CELLS MALAYSIA

- Located in central Malaysia close to Kuala Lumpur
- Manufacturing of crystalline solar cells
- Production Capacity: 600 MWp (by end of 2010)
- Employees: ~ 700

LOCATION

- The park is designed for science and technology-based industries with residential amenities of 1,560 acres
- Close to universities and schools
- Sufficient space for expansion
- Q-Cells is the first tenant in this ‘Green Field’

Q-CELLS R&D AREAS

Areas of R&D expertise

systems
modules
cells
wafering crystallization

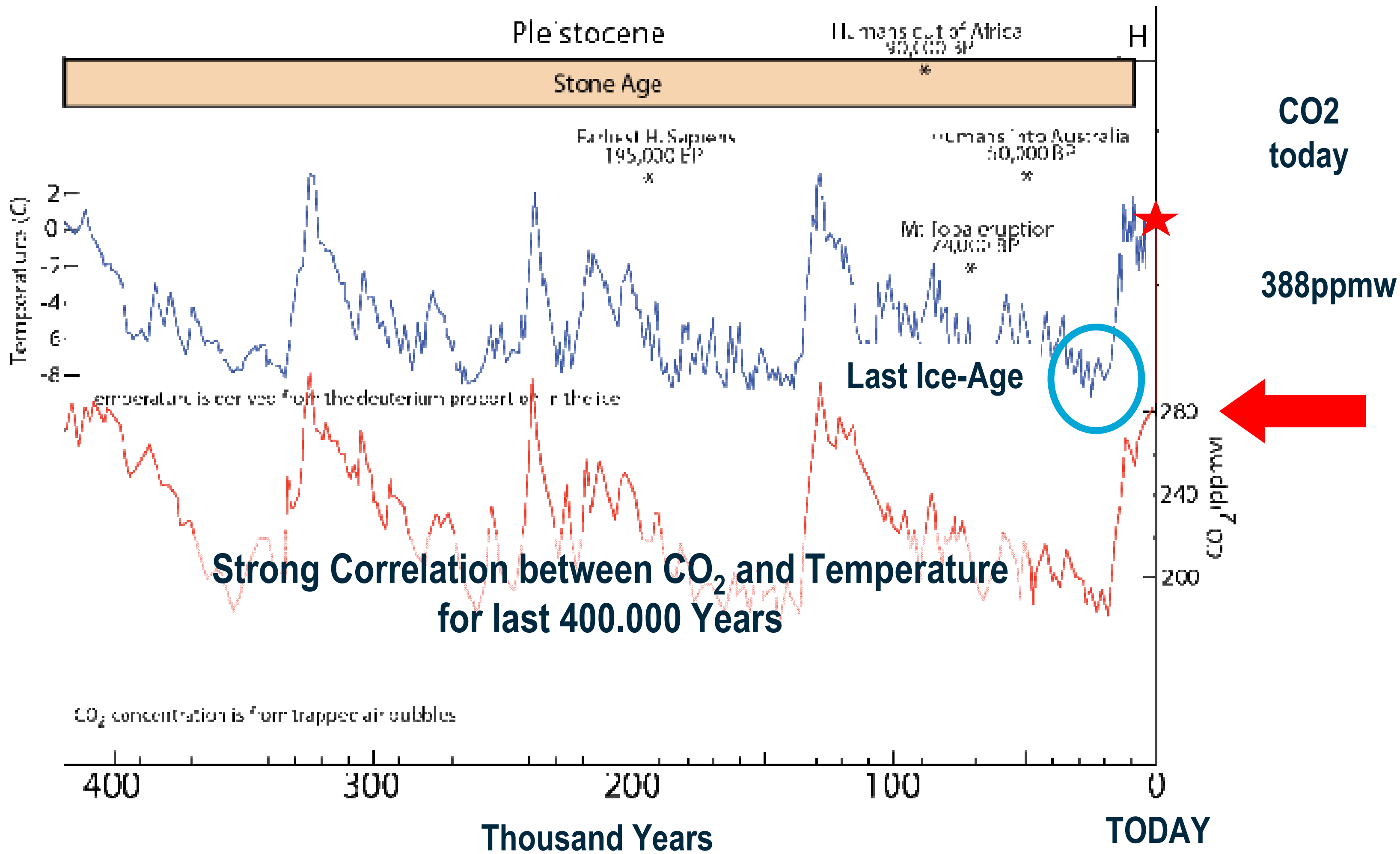
Outdoor system test facility
QCI systems for power plants
Outdoor module test facility
Module R&D, Research Line & Reliability Lab
Reiner Lemoine Reseach Center
Cell Development
R&D Cells Department
R&D Materials Group

2000	2002	2004	2006	2008	2010	2012	2014

→ Q-Cells R&D covering value chain, current R&D staff ~ 200

CONTENT

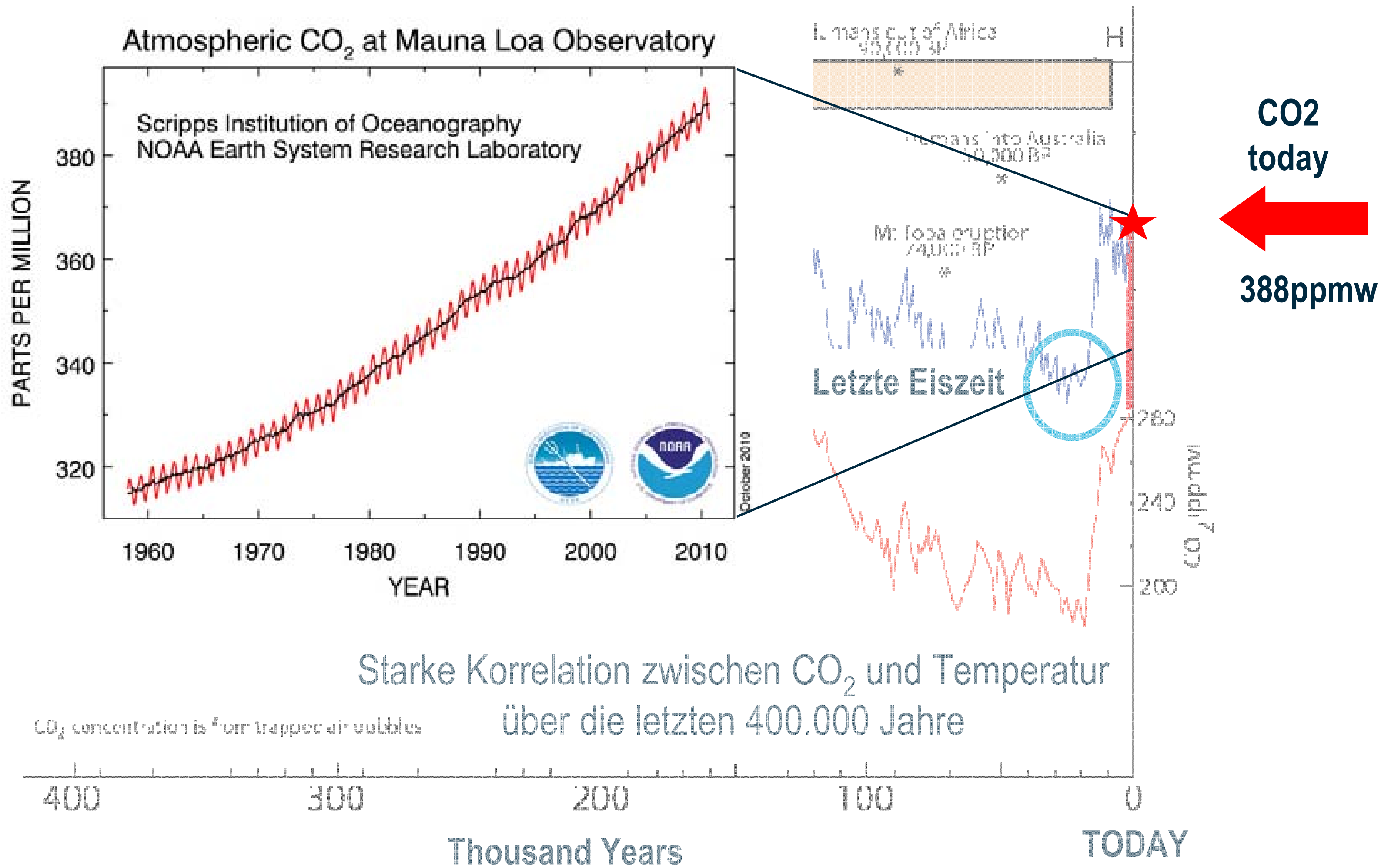
WHY RENEWABLE ENERGIES?



Source: Petit et al., Nature, 1999 Siegenthaler et al., Science, 2005; 21 December 2006

Temperature data from Vostok core CO_2 data from four ice cores

WHY RENEWABLE ENERGIES?



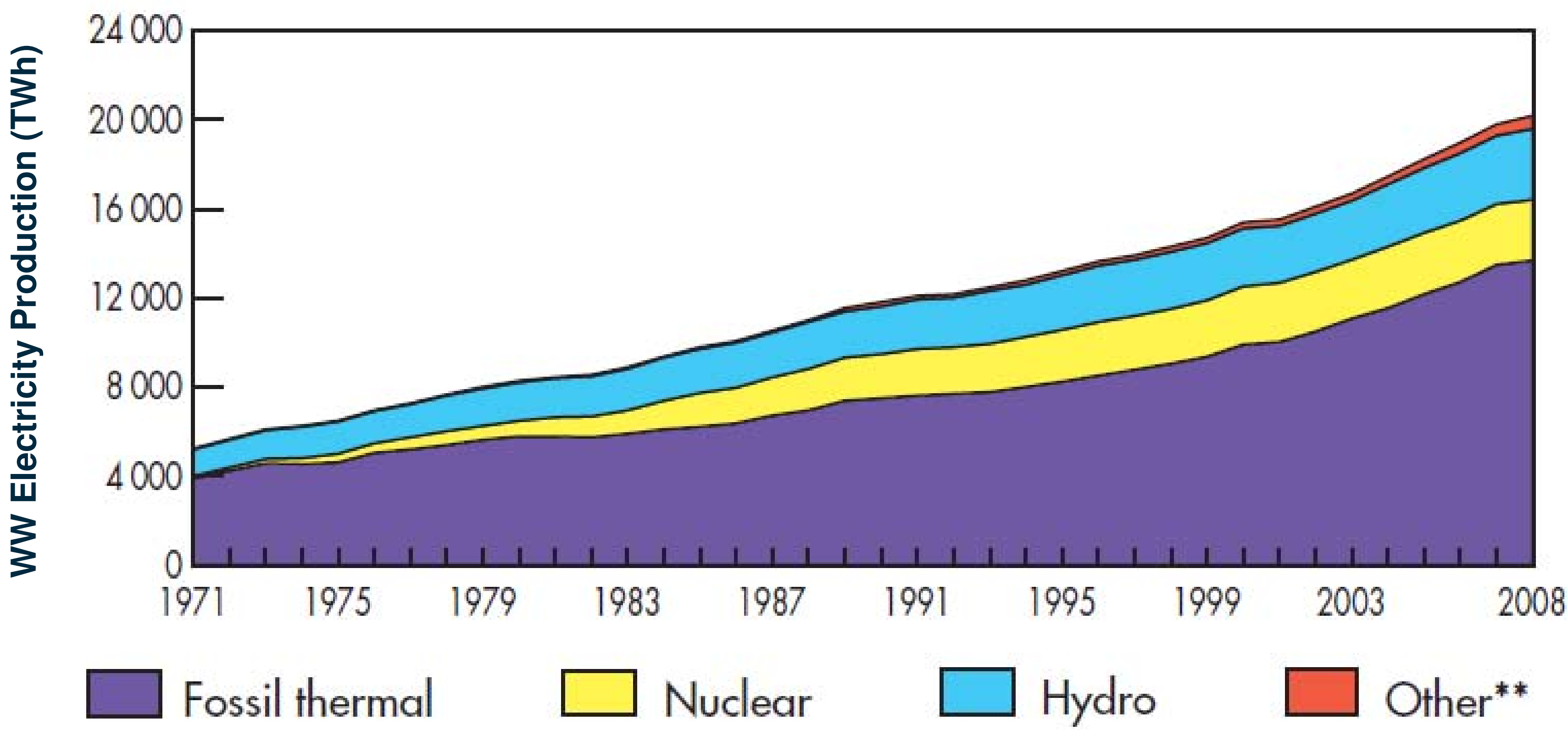
Source: Petit et al., Nature, 1999 Siegenthaler et al., Science, 2005; 21 December 2006

Temperature data from Vostok core CO_2 data from four ice cores

WHY RENEWABLE ENERGIES?

Oberer Gletscher - Grindelwald

GLOBAL ELECTRICITY PRODUCTION [TWh]



Worldwide Energy Demand is Mainly Based on Fossil Fuels
BUT: Renewables are Fastest Growing Source for Electricity Generation

Source: IEA Key - Statistics 2010

***Other includes geothermal, solar, wind, combustible renewables and waste, and heat.*

WORLDWIDE ELECTRICITY DEMAND
EXAMPLE CHINA

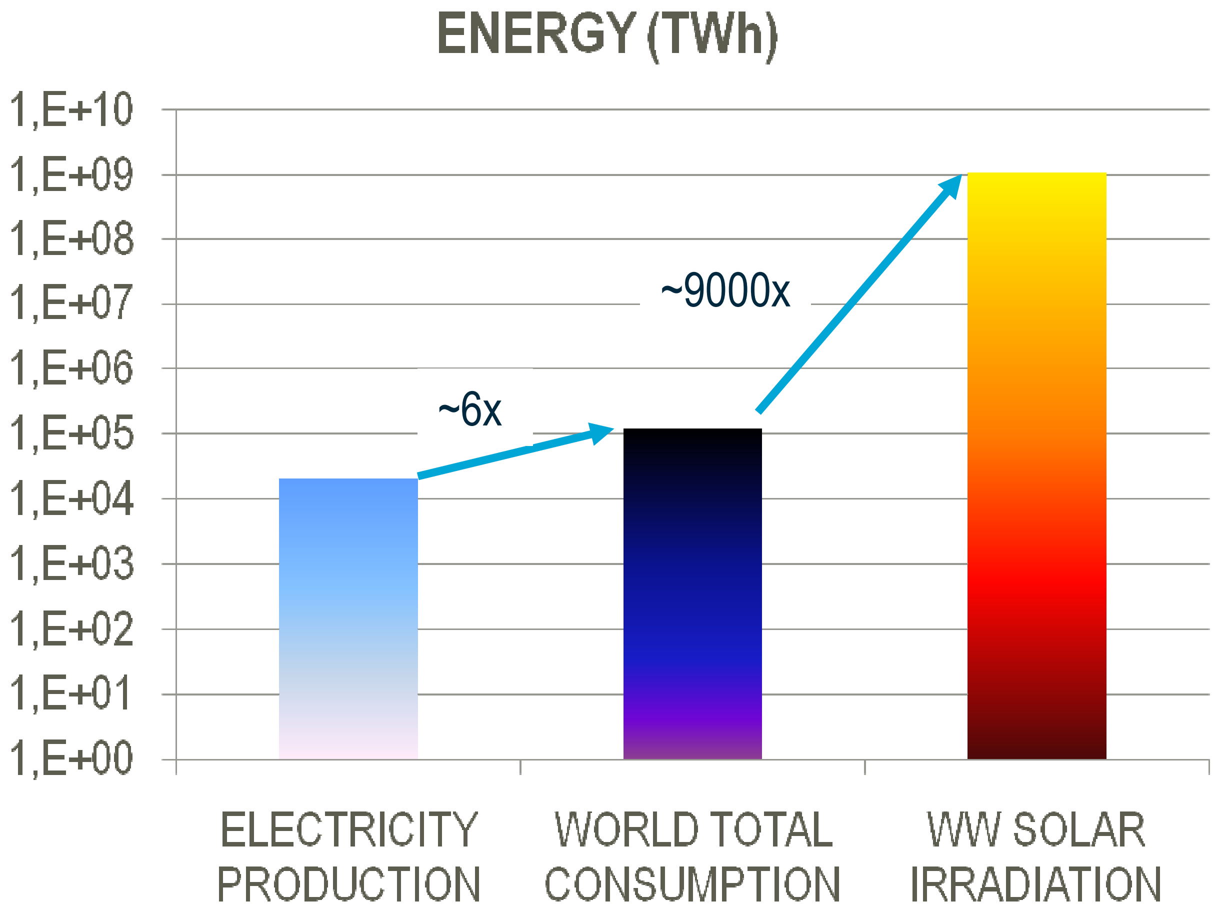
Electricity Generation of
1 Typical Powerplant:
1000MW x 8000h pa
= 8 TWh pa

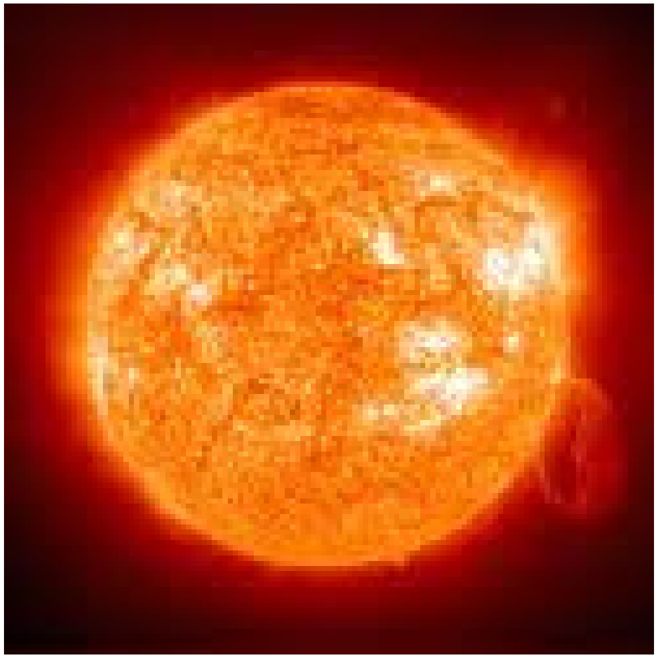
China 2020:
9819 TWh i.e.
+6328 TWh
compared to 2008

China 2008 – 2020:
+6328 TWh / 8TWh =
+791 Powerplants
of 1000MW-Class

+6328 TWh Equals ~10x of Total German Electricity Production of 615 TWh in 2008

WORLDWIDE ENERGY DEMAND AND SOLAR IRRADIATION





CONVERSION OF ENERGY FROM THE SUN: PHOTOVOLTAICS

Sun
*~1000**
kWh/m^2 a

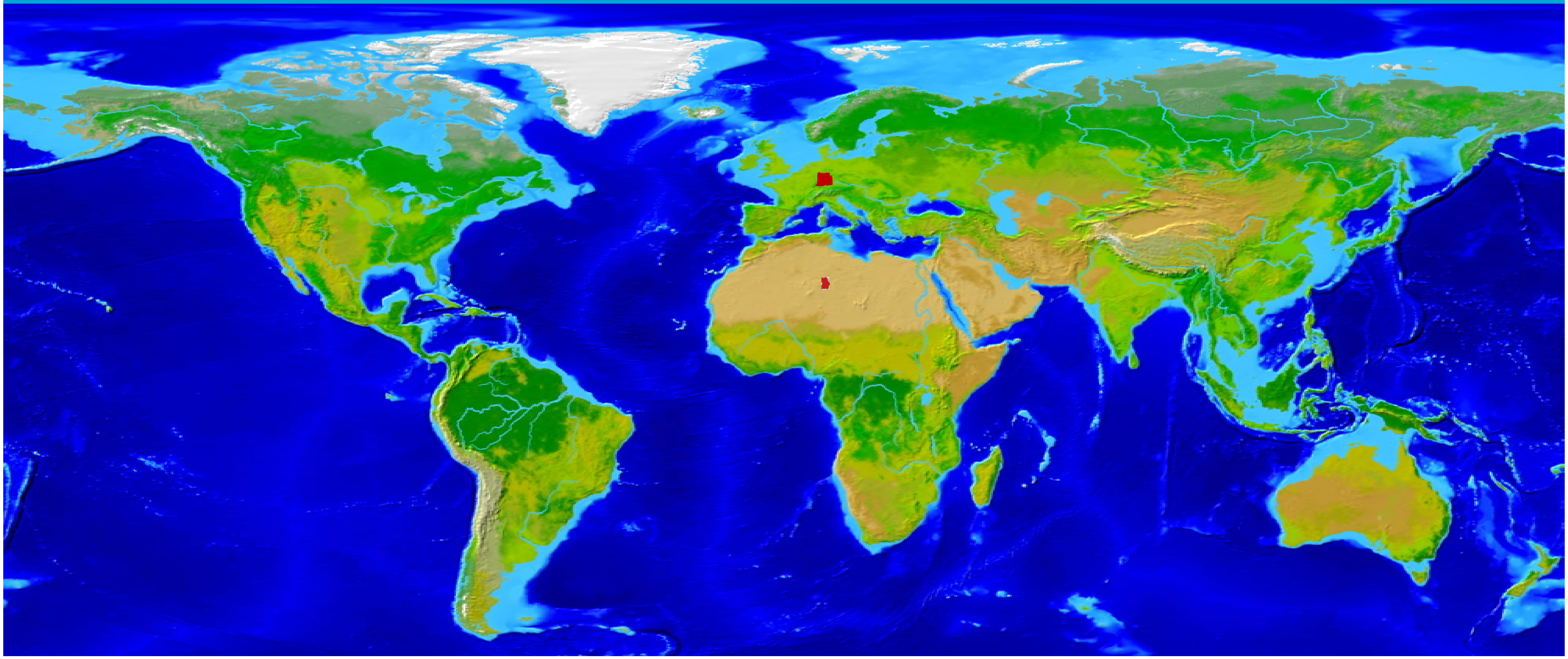
DIRECT CONVERSION

Electricity *~130kWh/m^2 a*

791 x 1 GW power plants =
220 x 220 km² of solar pannels

**Deutschland und Mitteleuropa, Südeuropa ~1700kWh/m^2 a,Sahara ~2350kWh/m^2 a*

SOLAR IRRADIATION: 1.08 x 10^9 TWh pa = 9.000x OF WORLD ENERGY DEMAND OF ~117.300 TWh/a



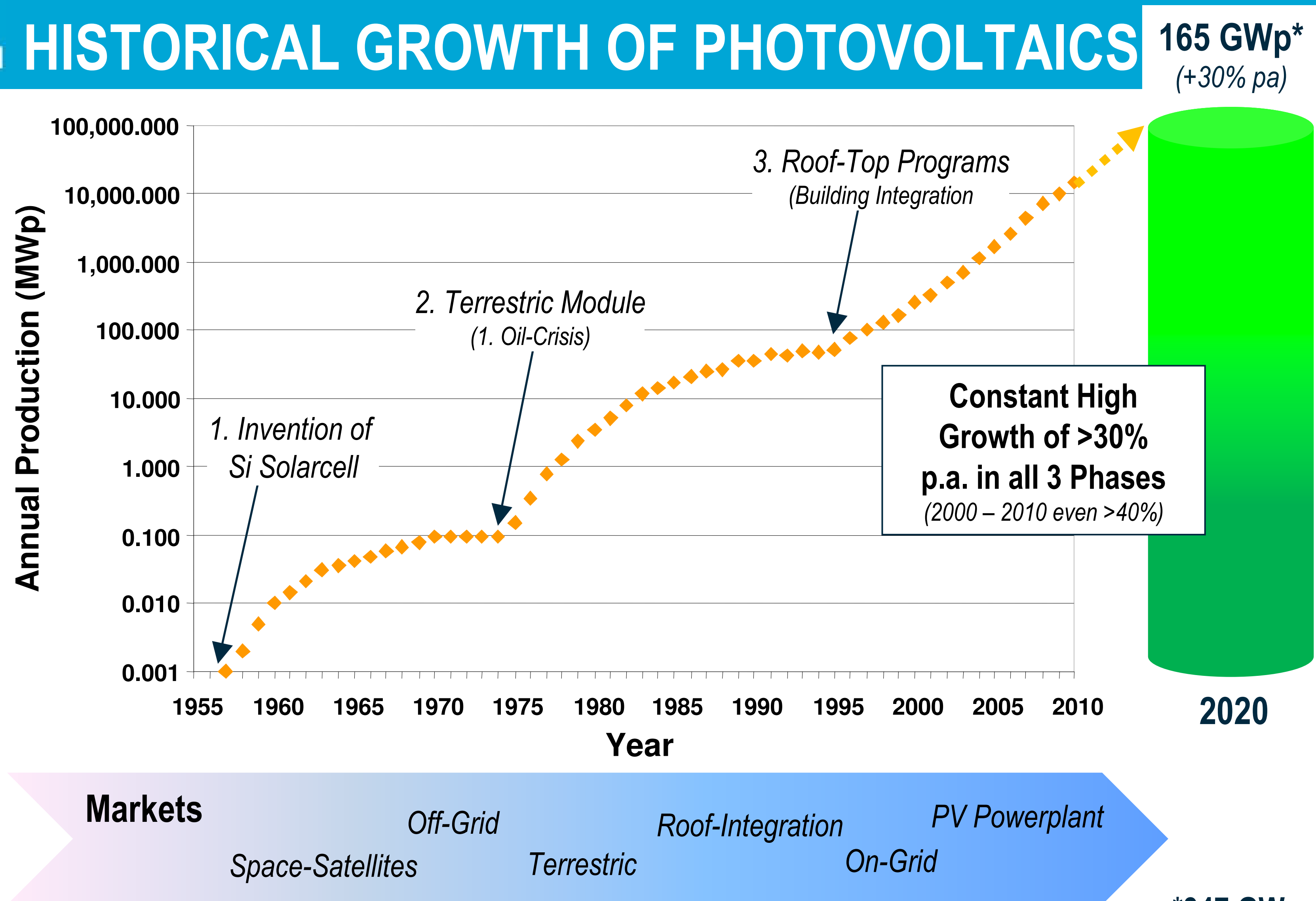
WORLDWIDE Electricity Demand of ~20.200 TWh/a is Produced by a PV-System* of:

Germany	→ ~1000 kWh/m^2 a	→	**155.300 km^2**	= 44% of Germany
WW-Average	→ ~1500 kWh/m^2 a	→	**103.500 km^2**	
Sahara	→ ~2300 kWh/m^2 a	→	**67.500 km^2**	= Bavaria (70.551 km^2)

Worldwide Rooftops ~ 375.000 km^2 (~2,5‰ of Earth Surface)

*Efficiency 13%

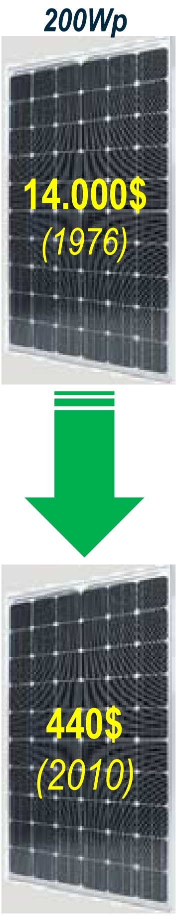
HISTORICAL GROWTH OF PHOTOVOLTAICS

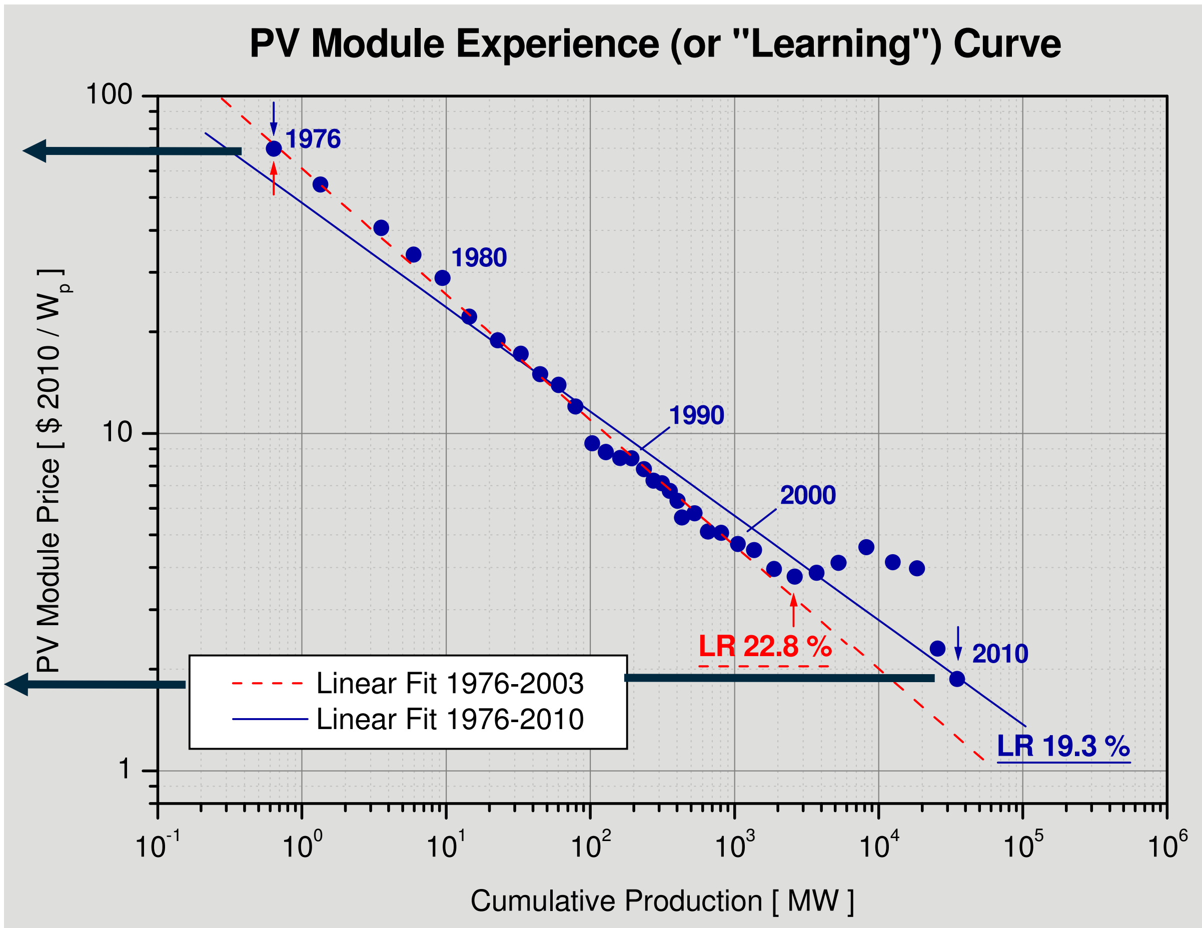


*347 GWp
(+40% pa)

source: Ch. Breyer et al., Research and Development Investments in PV – A limiting Factor for a fast PV Diffusion?, 25th EU PVSEC/ WCPEC-5, Valencia 2010, September 6 – 10

THE PV LEARNING-CURVE





PV 80% LEARNING-CURVE

Doubling of Cumulated Volume Produced

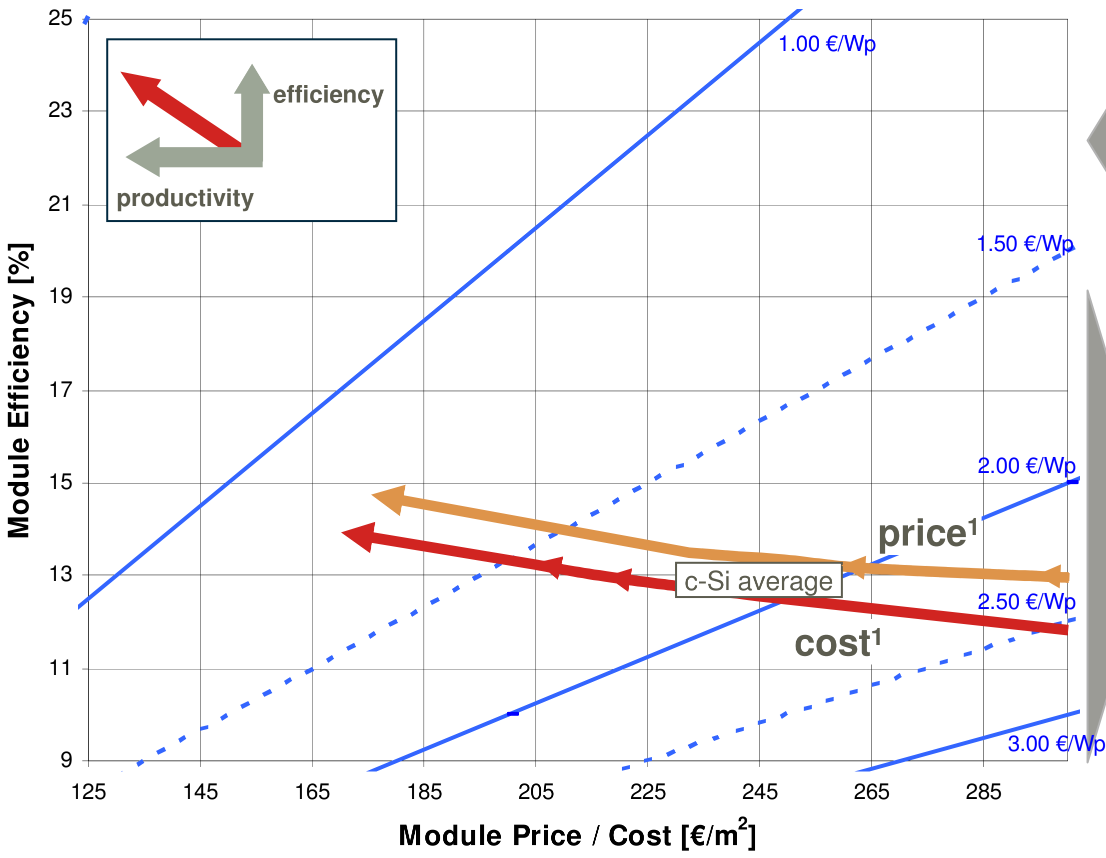
-20% COST Reduction

PV WILL BECOME LOW(EST) COST ELECTRICITY SOURCE

Sources: QC Research, PHOTON, EPIA, NREL, Solarbuzz, Strategies Unlimited, P. Maycock

SOLAR MODULES: EFFICIENCY & COST

Efficiency-Cost dynamics (schematic)



- Solar electricity cost €/kWh determined mainly by
  - <u>invest per installed system power</u>
  - local level of solar irradiation
  - cost of capital etc.

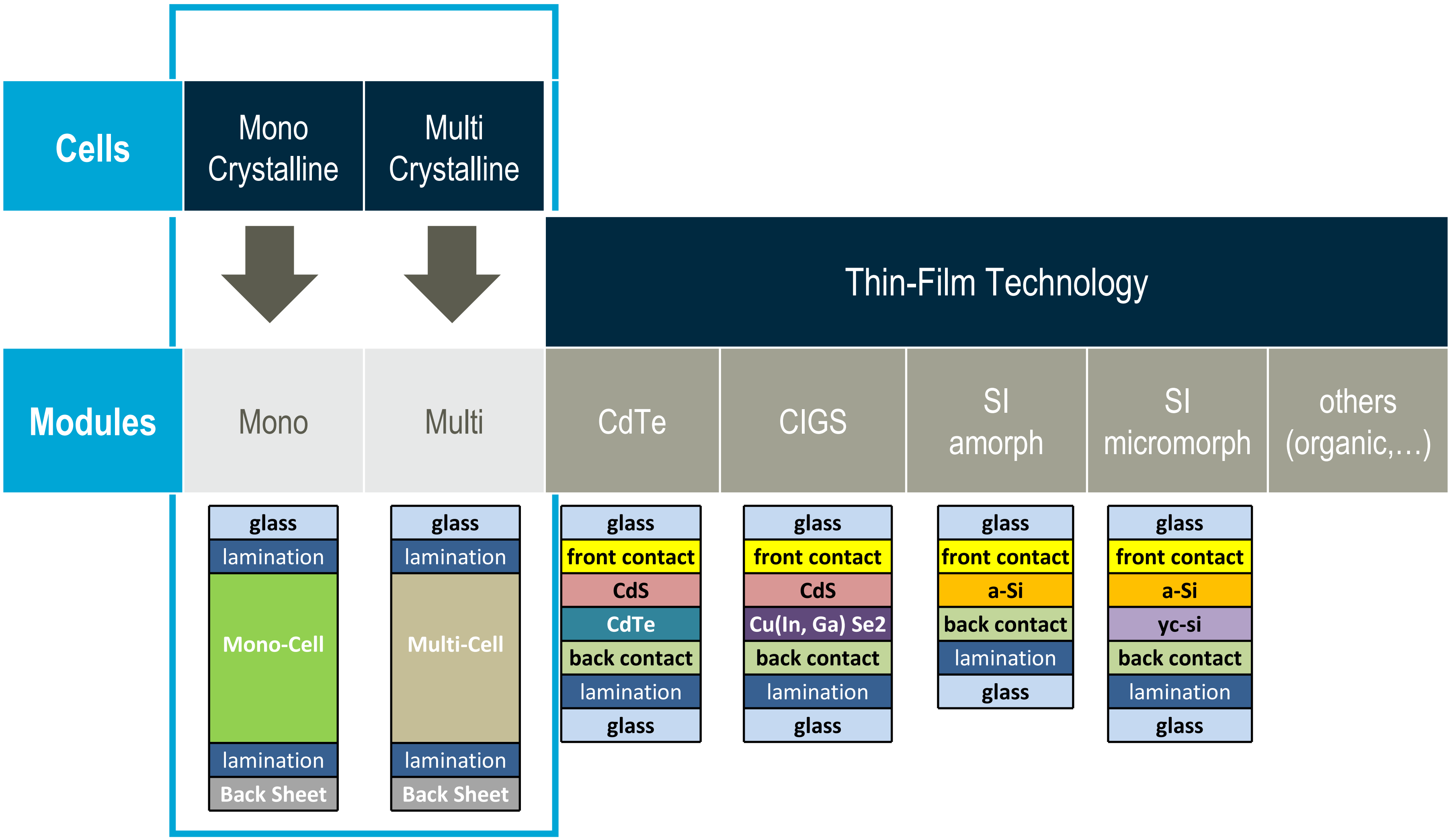
Major factors determining the reduction of cost per Wp and LCoE (€/kWh):

1. reduction of area cost
2. increase in module efficiency

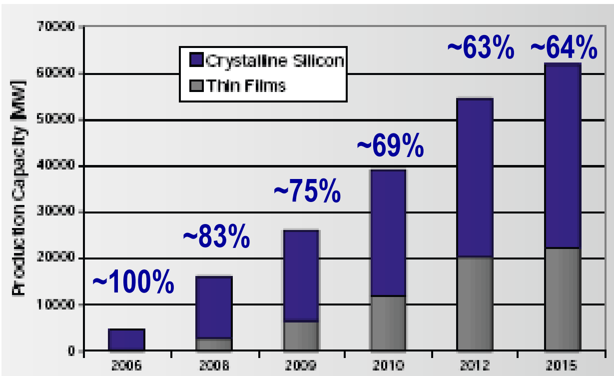
[1] avg. fully loaded Si module cost & avg. spot price Si module, Sources: Q-Cells, DB, DnBNOR, Photon Solar Updates

CONTENT

OVERVIEW – PV TECHNOLOGIES

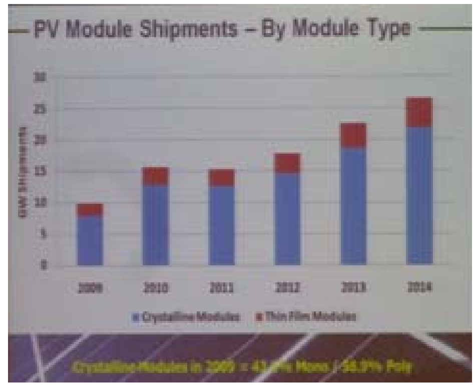


C-SI & THINFILM PRODUCTION SHARES



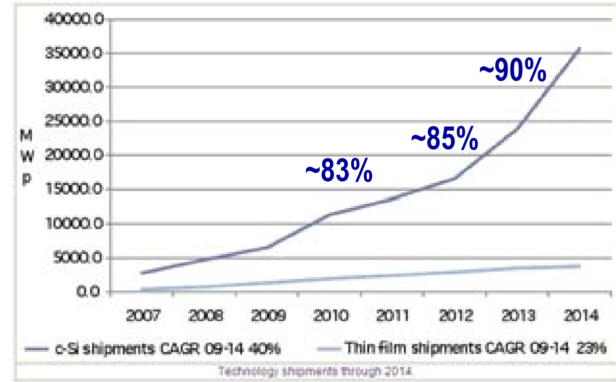
PV Status Report 2009: c-Si share ~ 2/3

Source
PV Status Report 2009
Research, Solar Cell Production and Market Implementation of PV
European Commission, Institute for Energy



IMS Research: c-Si share ~ 80%

Source
Paula Mints, Navigant Consulting,
Sept 17,2010



Navigant Consulting: c-Si share ~ 85%

Source
Paula Mints, Navigant Consulting,
Sept 17,2010

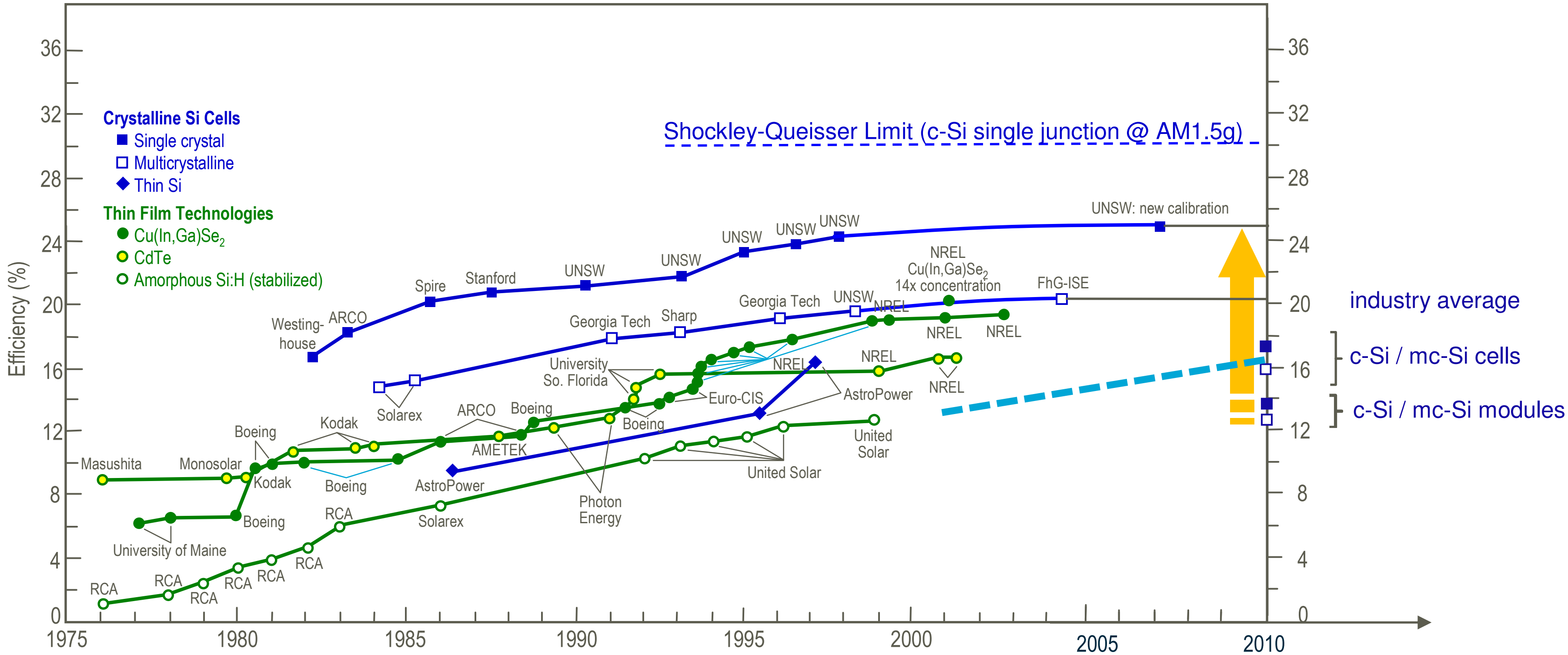
→ c-Si Will Remain Dominant Technology for the Years to Come (~80%)

- **Maturity of c-Si technology and production equipment/availability support further volume growth**
  (thin film technologies still mainly based on proprietary technology/equipment)
- **High volumes sustain c-Si scaling effects for further cost reductions**
- **Expectations also reflect relaxed Si supply situation with respect to availability of raw material**

EFFICIENCY HEADROOMS SET BY RESEARCH CELL EFFICIENCIES

NEREL data on solar energy conversion efficiencies

Record research cell efficiencies



→ Efficiency headroom of etablished concepts support further evolutionary dev‘t

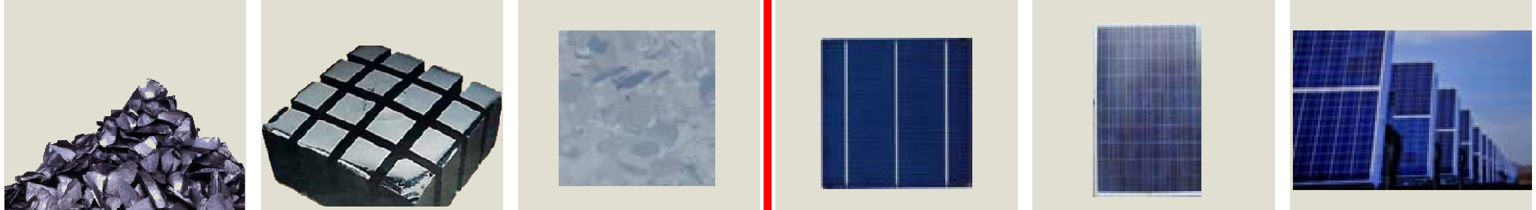
→ Focus on innovation transfer to mass production rather than on disruptive technologies

Sources: adapted from NREL, Green Efficiency Tables

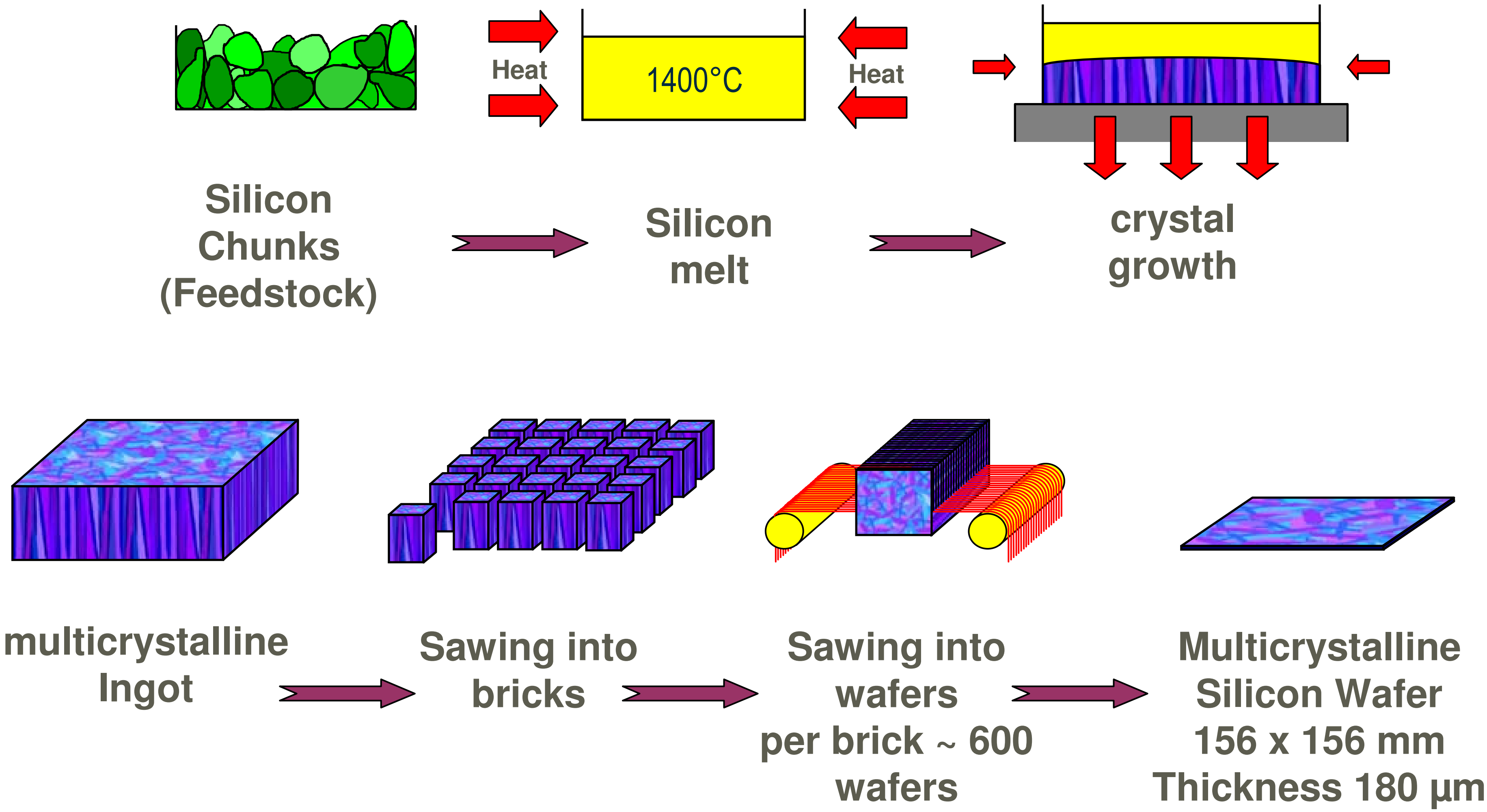
C-Si TECHNOLOGY ALONG THE VALUE CHAIN

Q-Cells Positioing along the Silicon value-chain

	SILICON	CRYSTAL.	WAFER	CELL	MODULE	SYSTEM
Q-Cells	R&D	R&D	R&D	R&D and Production	R&D and Production	R&D and Projects



FROM SILICON TO WAFER



TYPICAL SILICON MANUFACTURING PLANT

Production of High Purity Silicon based on Fractional Distillation of SiHCL3 According to SIEMENS Process

PV INGOT MANUFACTURING

PV INGOT MANUFACTURING

Ingot 450kg

↓

25 Bricks

18kg each

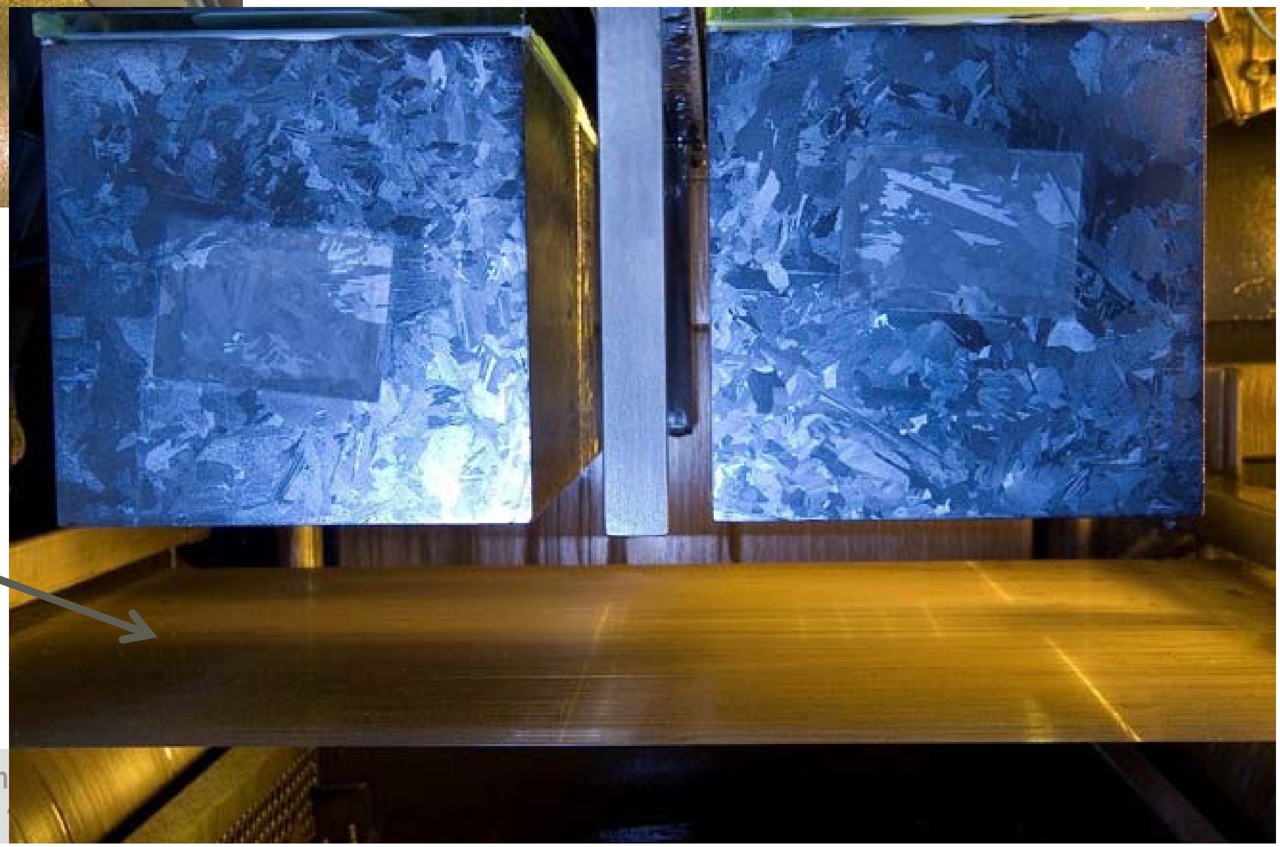
1kg = 40 wafer

→ 25 x 18 x 40

= 18.000 wafer/ingot

PV SILICON WIRESAW FOR WAFERING

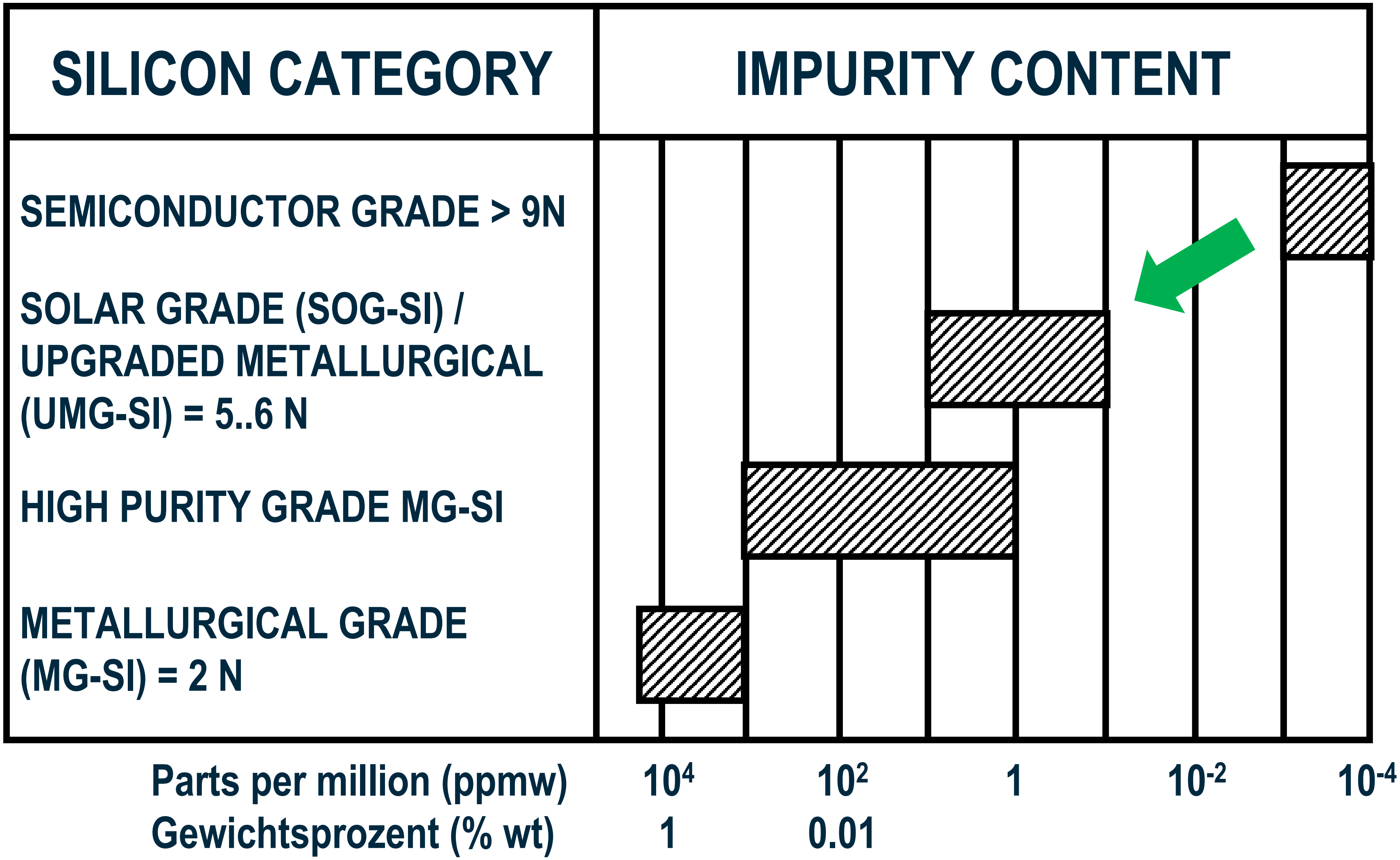
Bricks



Wire

Wafer Thickness ~180µ

Impurity concentration in different Silicon Qualities



COST REDUCTION POTENTIAL SOLAR GRADE SILICON (UMG-SI)

metalurgical Si: 99% purity (2N)
upgraded mg-Si >99.999% (5-6N)
poly-Si (electr. grade) (> 9N)

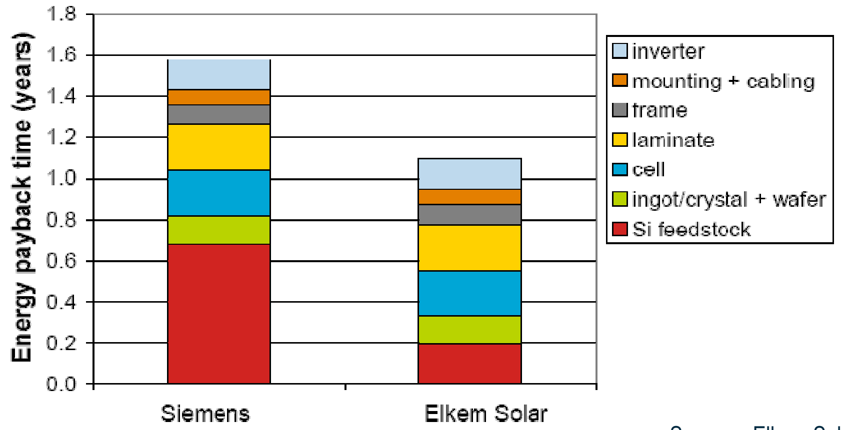
Advantages

- lower cost
- lower energy consumption
  - → "greener product"
  - → decreased energy payback time
- significant learning curve:
  umg-Si cell efficiencies close to multi cells

Challenges

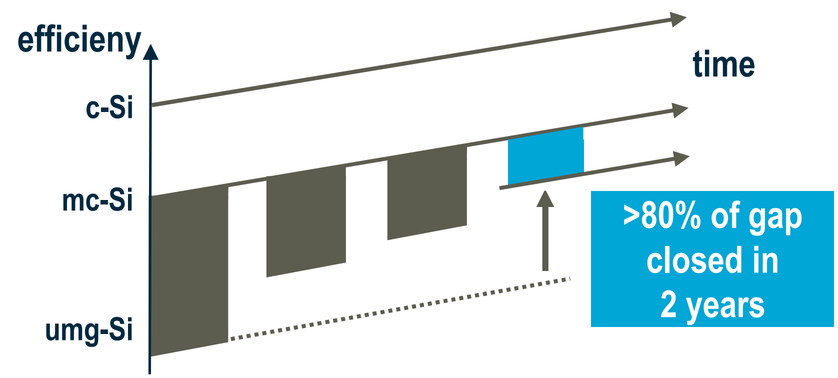
- Stable process / mass production

PV energy payback time (southern Europe)



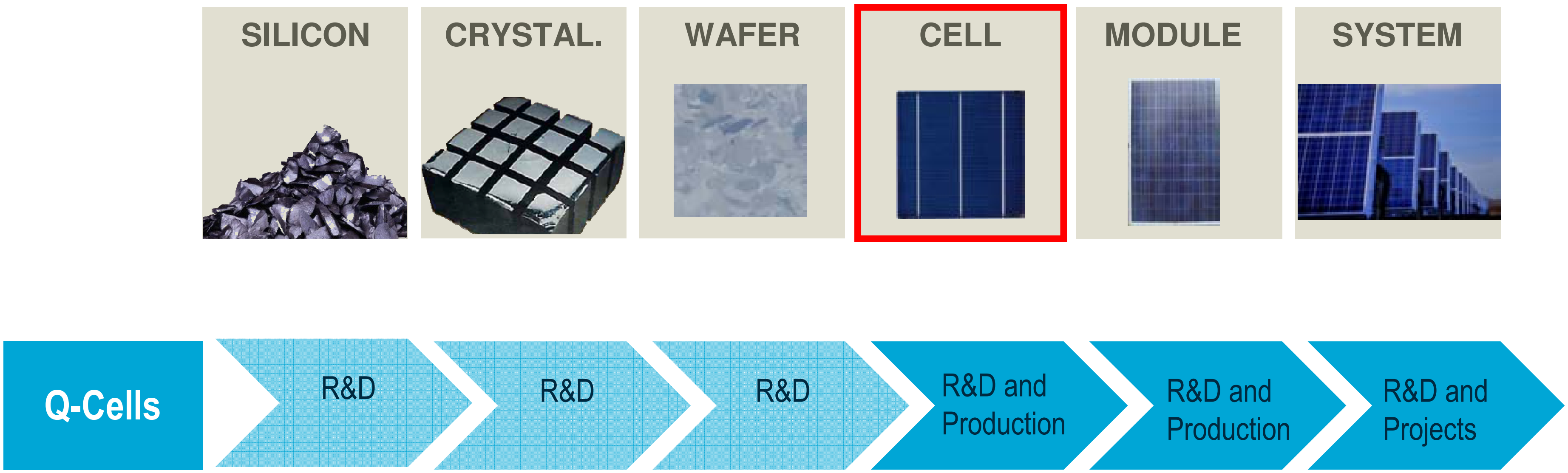
Sources: Elkem Solar

umg-Si devm't progress

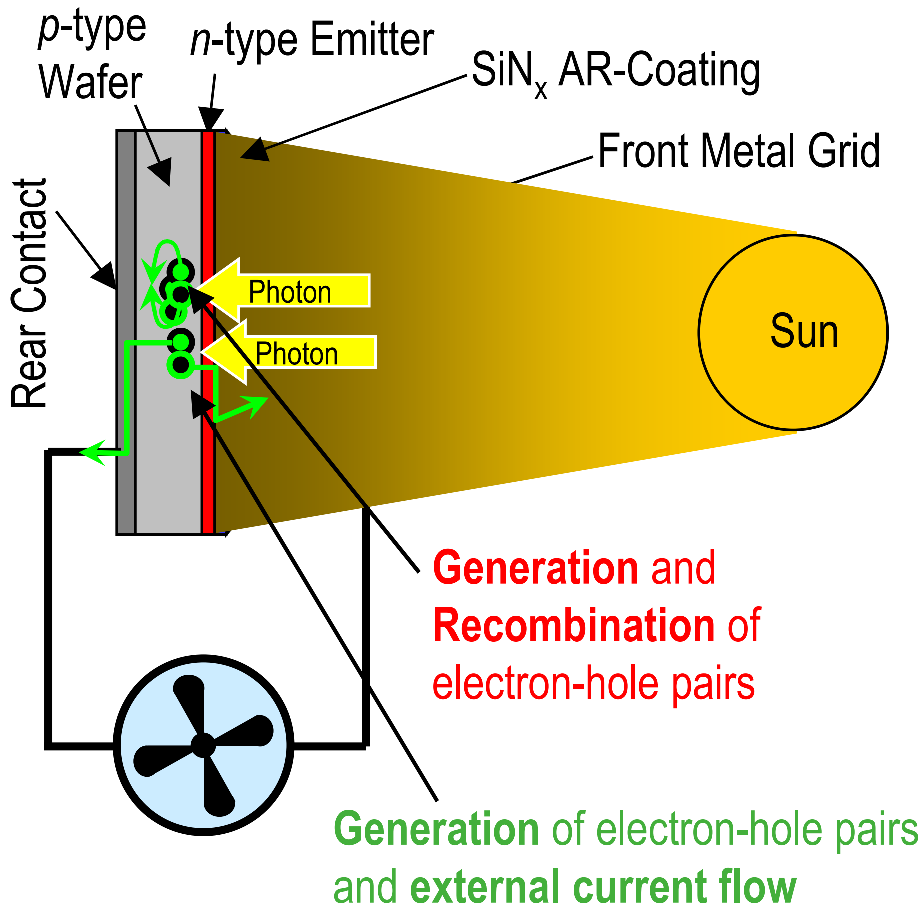


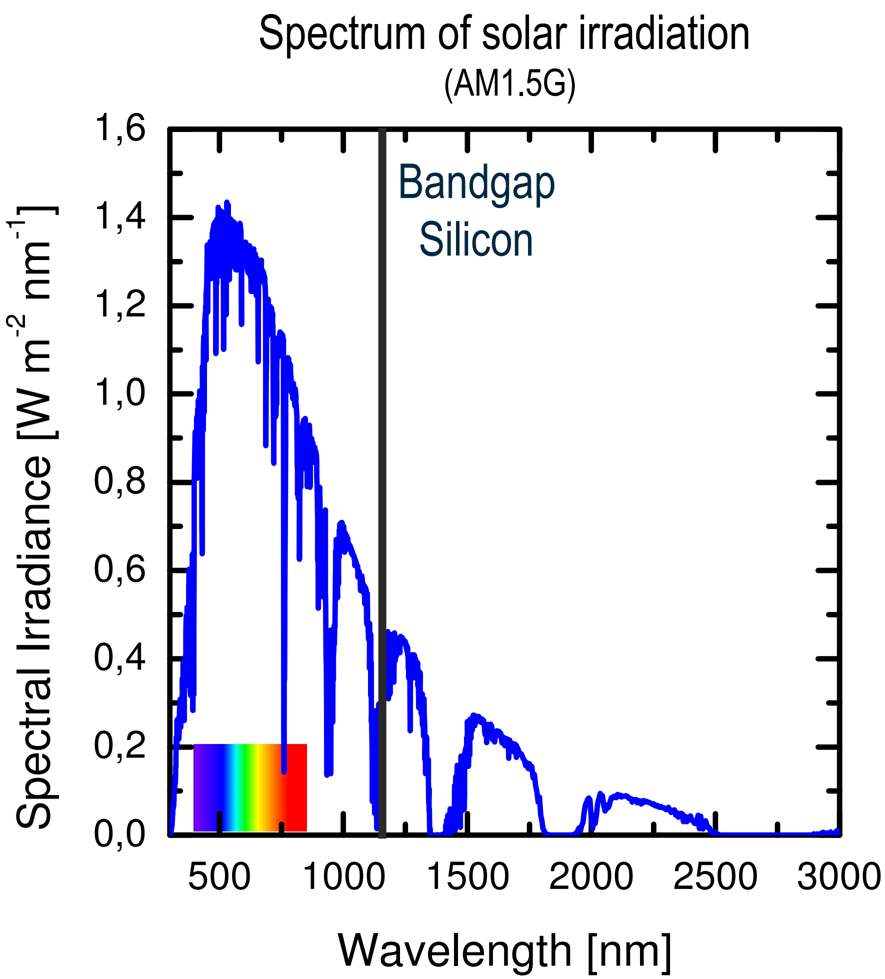
C-Si TECHNOLOGY ALONG THE VALUE CHAIN

Q-Cells Positioing along the Silicon value-chain



SILICON SOLAR-CELL BASICS





Q-CELLS CELL DEVELOPMENT

FRONT SIDE

contacts, finger width & shadowing

emitter profile, surface passivation

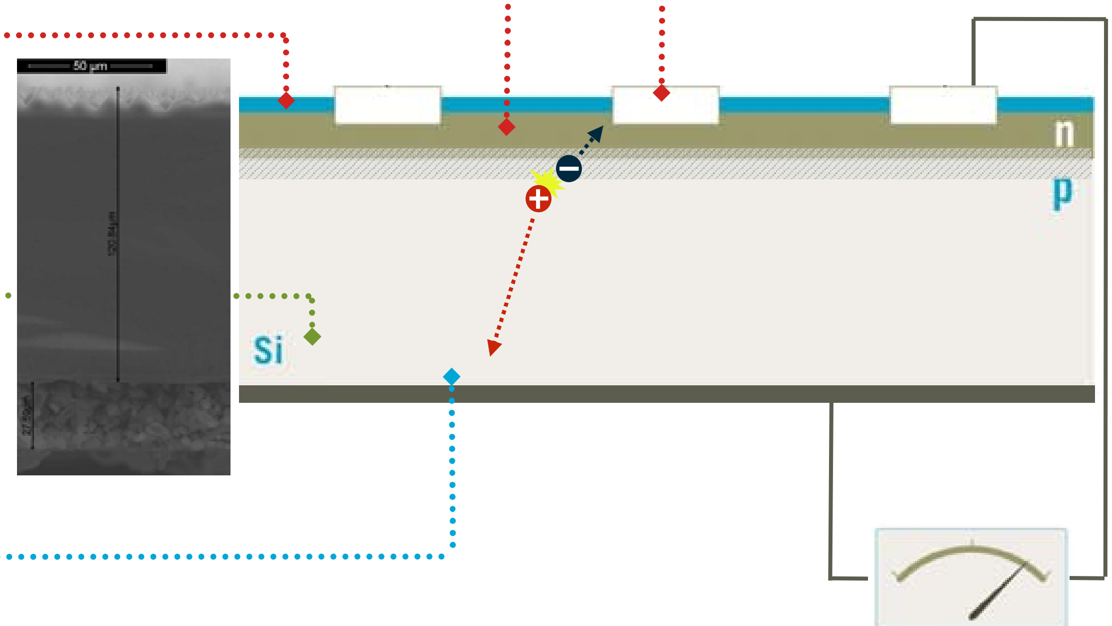
anti-reflection layer, texturization

BULK MATERIAL

improved material quality

REAR SIDE

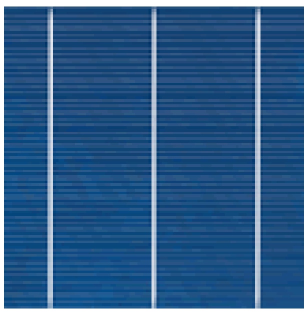
rear passivation & reflector



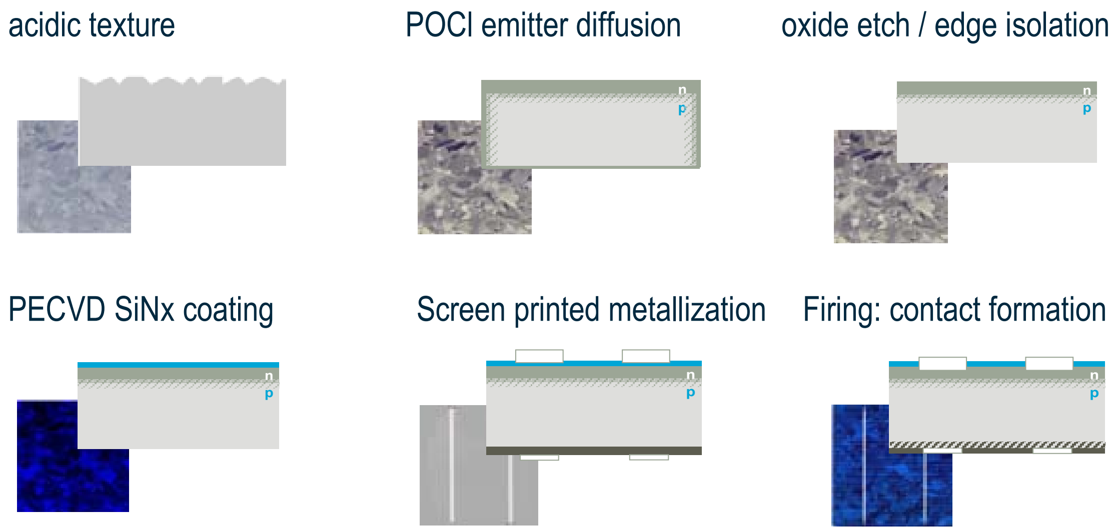
Optimized properties for maximum performance in efficiency and cost

Current Standard Process for multi c-Si Cells

standard cell in prod.



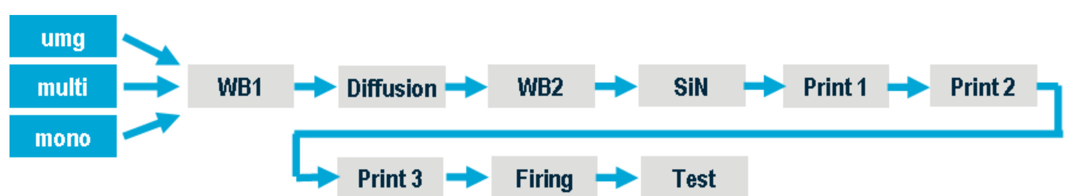
mc-Si : ~ 15.6 … 16.8%
fsq-mono-Si ~ 16.5 … 17.4%



Characteristics

- p-type Silicon
- Screen printed contacts w/ Ag paste at front
- Al back surface field w/t Al-Paste at back
- 3 BB

Sequence of processing

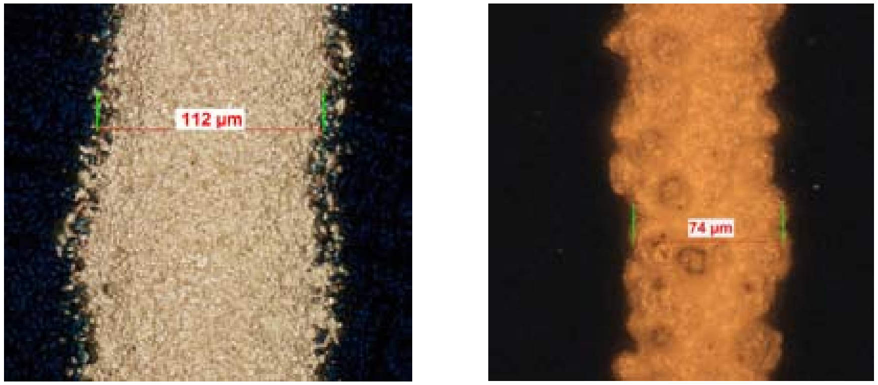


Fine line print

Target
- adapt metallization grid to modified emitter profile
- reduce front metallization shading

→ denser finger grid with reduced area coverage

Solutions
- **printing techniques**
  - optimized screen print
  - new printing techniques
    - aerosol printing
    - inkjet printing
- **seed & plate**
  - separate optimization
    - contact layer
      (seed – contact resistance, adhesion)
    - conducting layer
      (plate – conductivity, aspect ratio)



cross-section

metallization grid

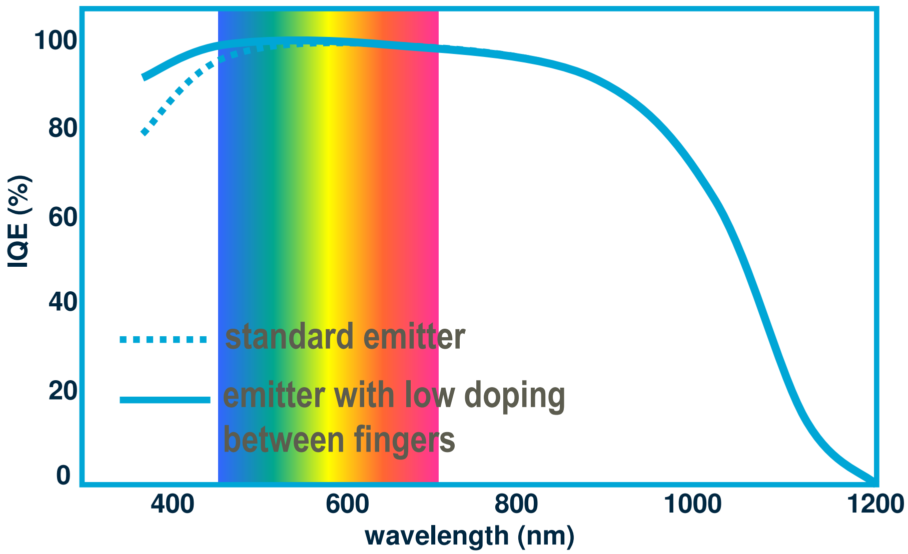
CELL FRONT SIDE

Emitter doping

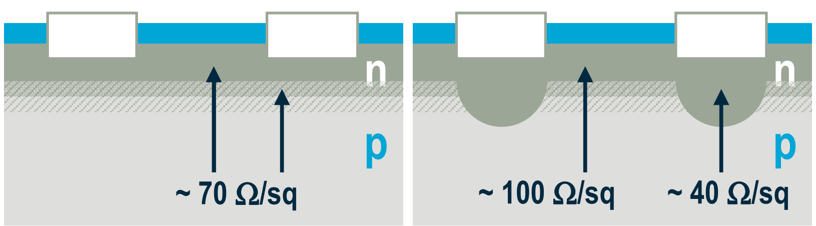
Target
- increased blue response
  (emitter doping reducing Auger recombination)

Solutions
- **low doped emitter**
  - emitter contact supported by paste
- **etch back**
  - reduce dopant surface concentration
- **selective emitter**
  - low doping level in between fingers
    → reduced recombination losses
  - high doping level beneath fingers
    → low contact resistance metal to emitter
  - alignment requirements (metal to doping) vs self-aligned techniques (e.g. plating)

increased blue response



low doped emitter | **selective emitter**



OPTIMIZED CELL CONCEPT: REAR SIDE

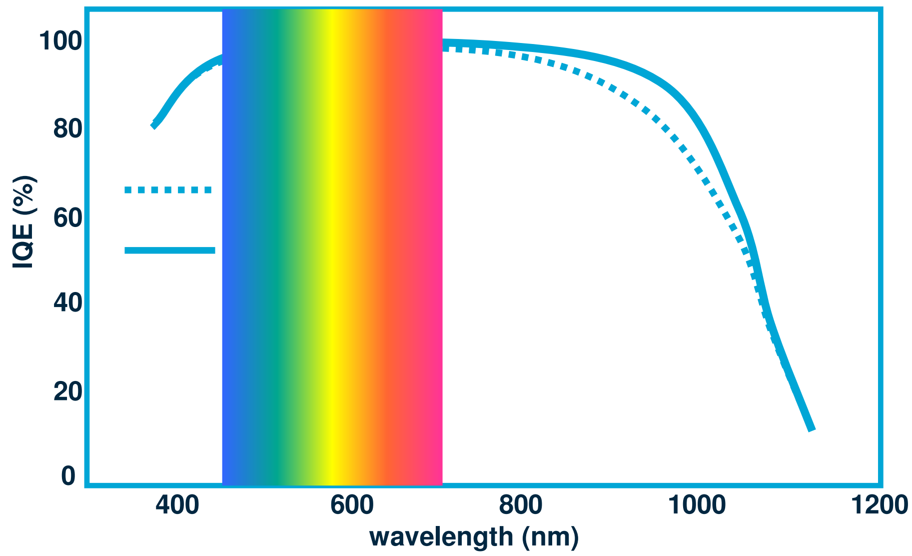
Rear Side + mirror & contacts

Targets

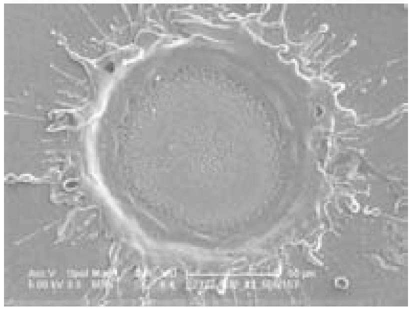
- overcome Al-BSF limitations
  - improve passivation
  - reduced bowing
  - enhance reflectivity
  - contact with limited area coverage for passivation layer integrity & efficiency

Approach

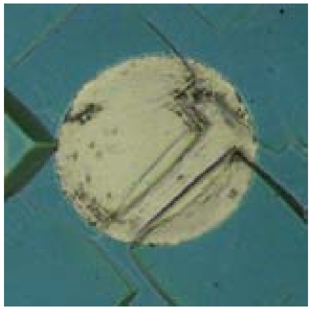
- rear passivation layer
  → Voc enhancement
- rear metallic mirror
  → Jsc enhancement
- **Rear dielectric and metallization**
  - e.g. SiN and Al evaporation
  - Al mirror / dielectric stack
- **Local contacts**
  - LFC (laser fired contact)
  - PERC / PERL
  - optimized contact area for best passivation and low Rs i.e. high FF



laser fired contact



PERC contact

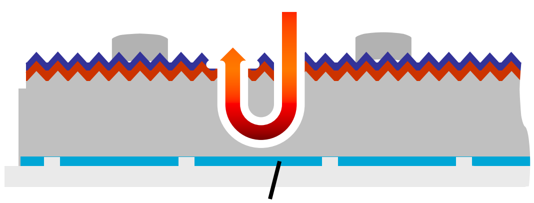


New cell concepts for reduced wafer thicknesses

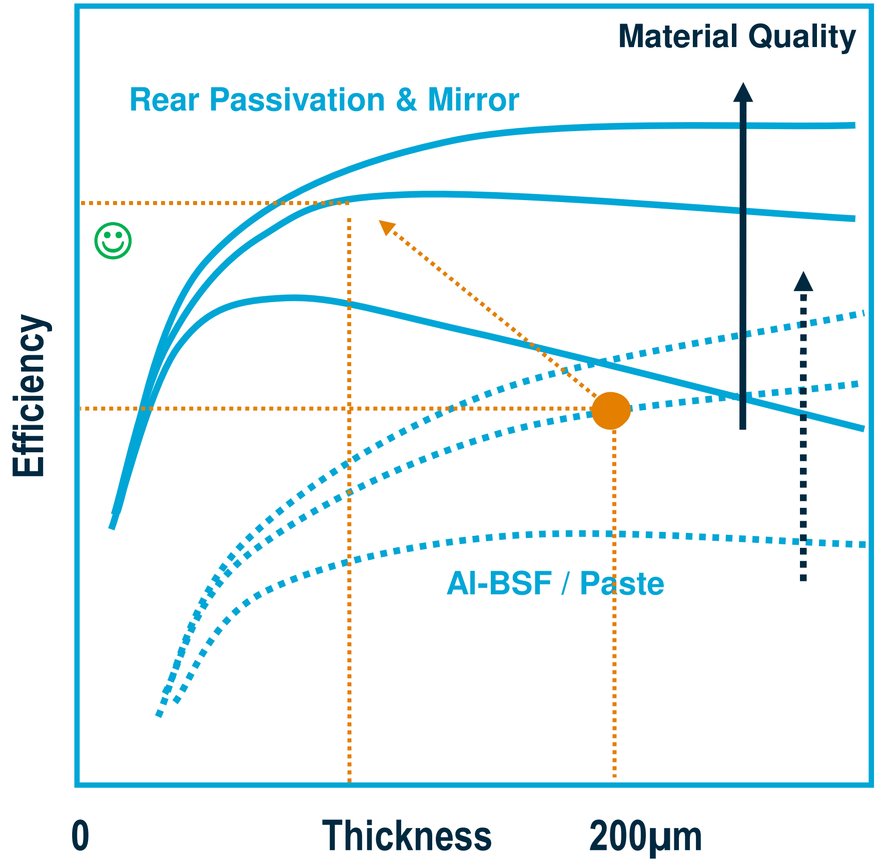
Reduced Silicon Thickness

Task
- Reduce amount of silicon used in terms of g/Wp
- Maintain / increase cell efficiency

Solution
- **Dielectric passivation & mirror**
  - take advantage of surface improvements
  - keep efficiency high in spite or reduced thickness due to rear mirror

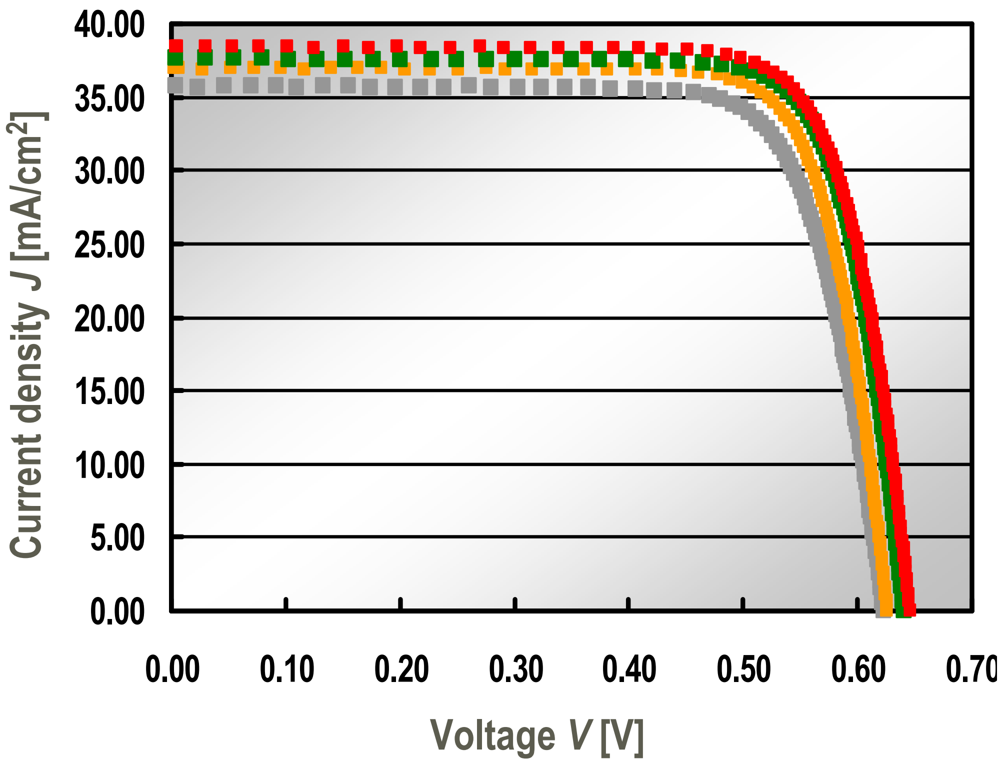


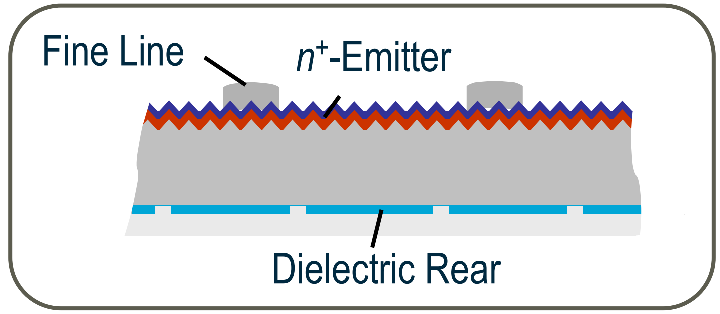
Dielectric Rear and Local Point Contacts (PERC)



→ Dielectric Rear Enables Wafer Cost Reduction AND Increased Efficiency

Q-CELLS ADVANCED CELL-CONCEPT RESULTS



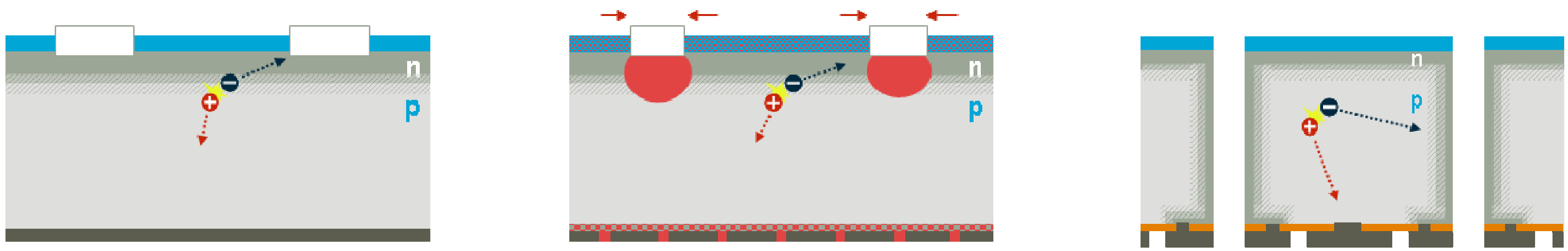


	V1 2008	V2 2009	V3 2009	V4 2010
V_{oc} [V]	624	627	642	646
J_{sc} [mA/cm²]	35,7	36,9	37,6	38,4
FF [%]	77,1	79,1	79,5	78,1
□ [%]	17,2	18,3	19,2	19,5

Q-Cells Dielectric-Rear Cell: Evolution from 17,3% to 19,5% for 6“ CZ Mono

OUTLOOK: REAR CONTACT CONCEPTS

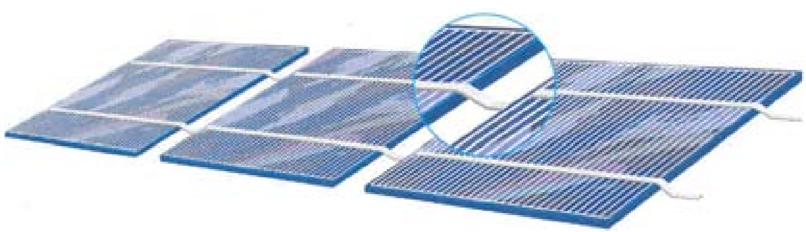
CELL

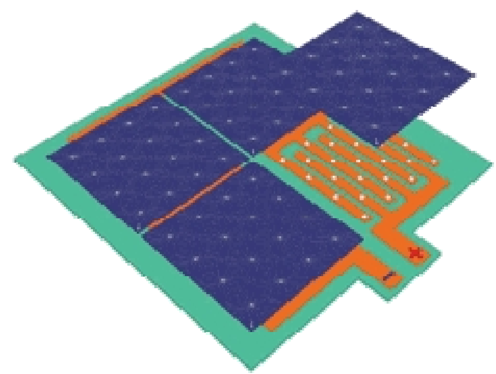


advanced

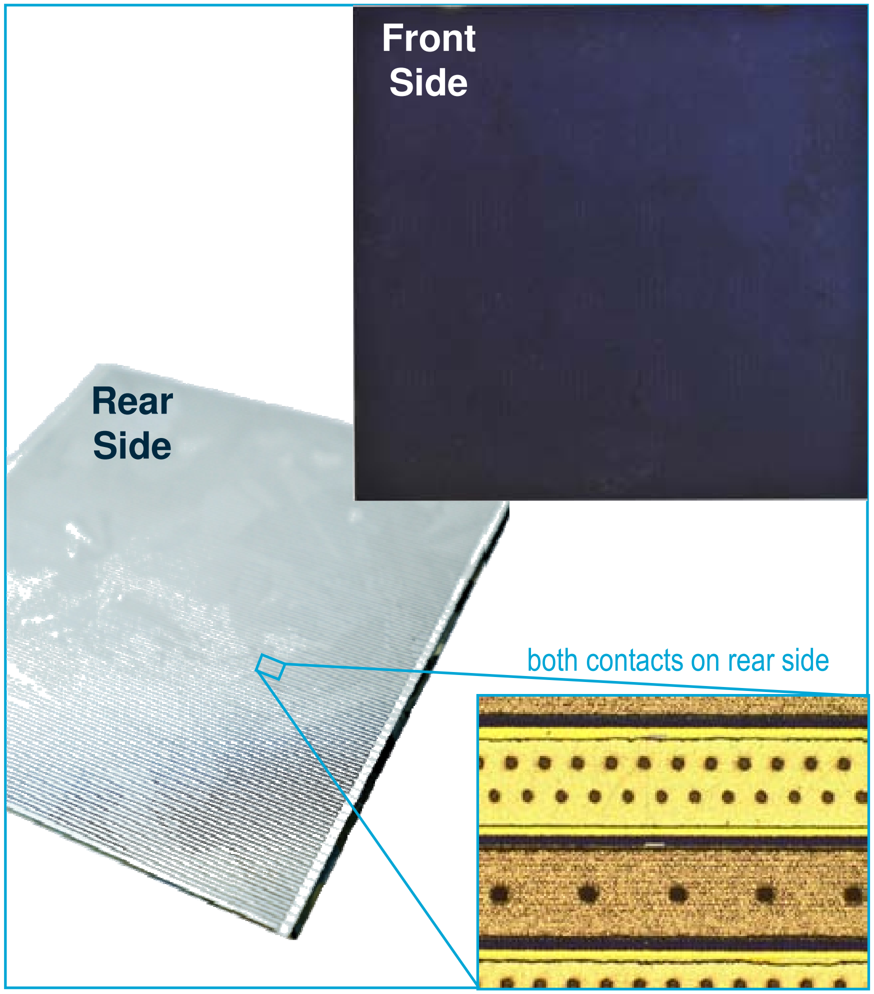
rear contact

INTERCONNECTION





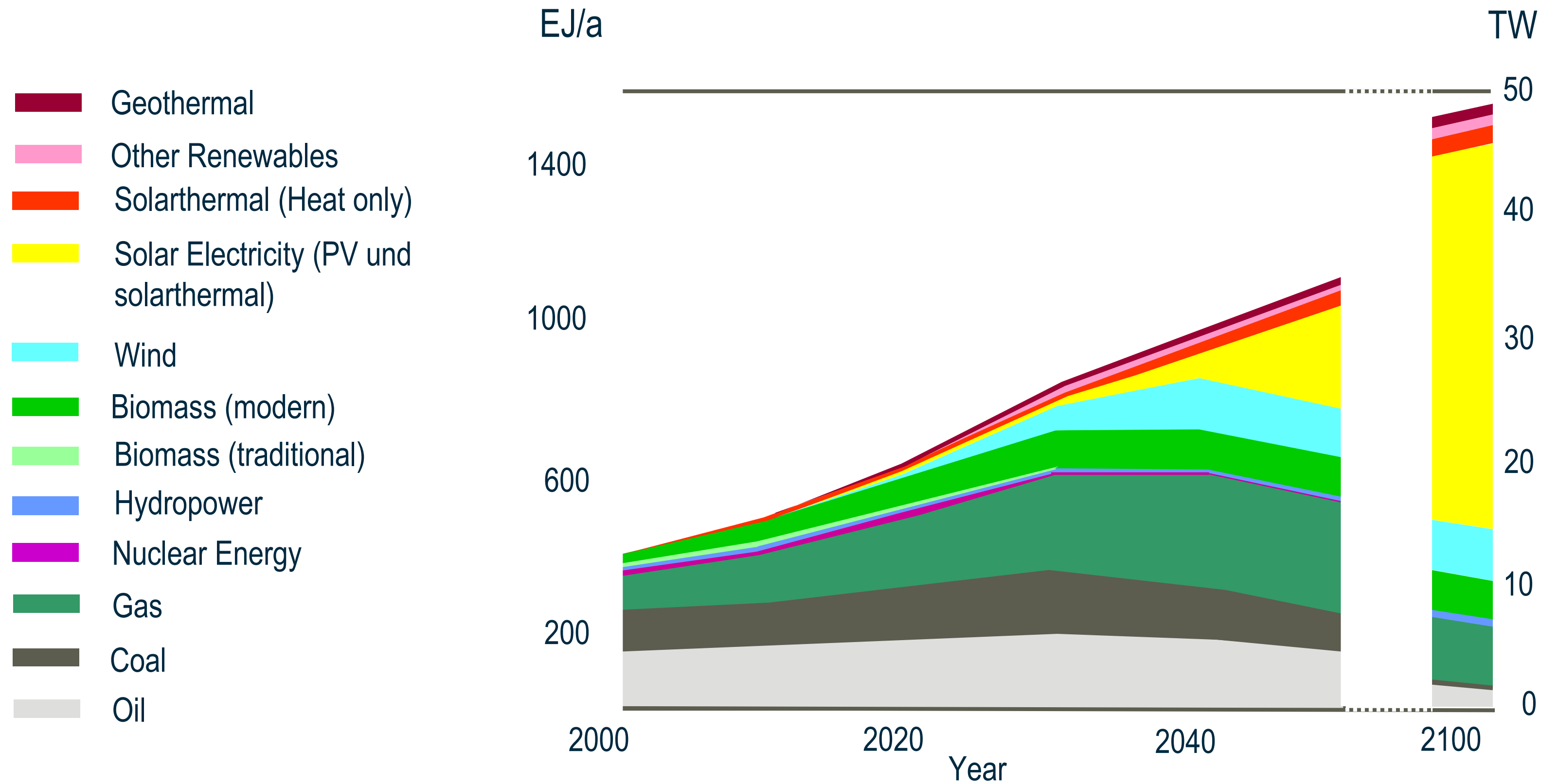
OUTLOOK: EMITTER-WRAP-THROUGH DESIGN



UNIQUE FEATURES

- Avoidance of grid shading
- Homogeneous appearance
- Silver-free metallization
- Advantegous module assembly
- Highly robust production process
- Flexibility in use of material
  - mono
  - multi
  - umg-Si

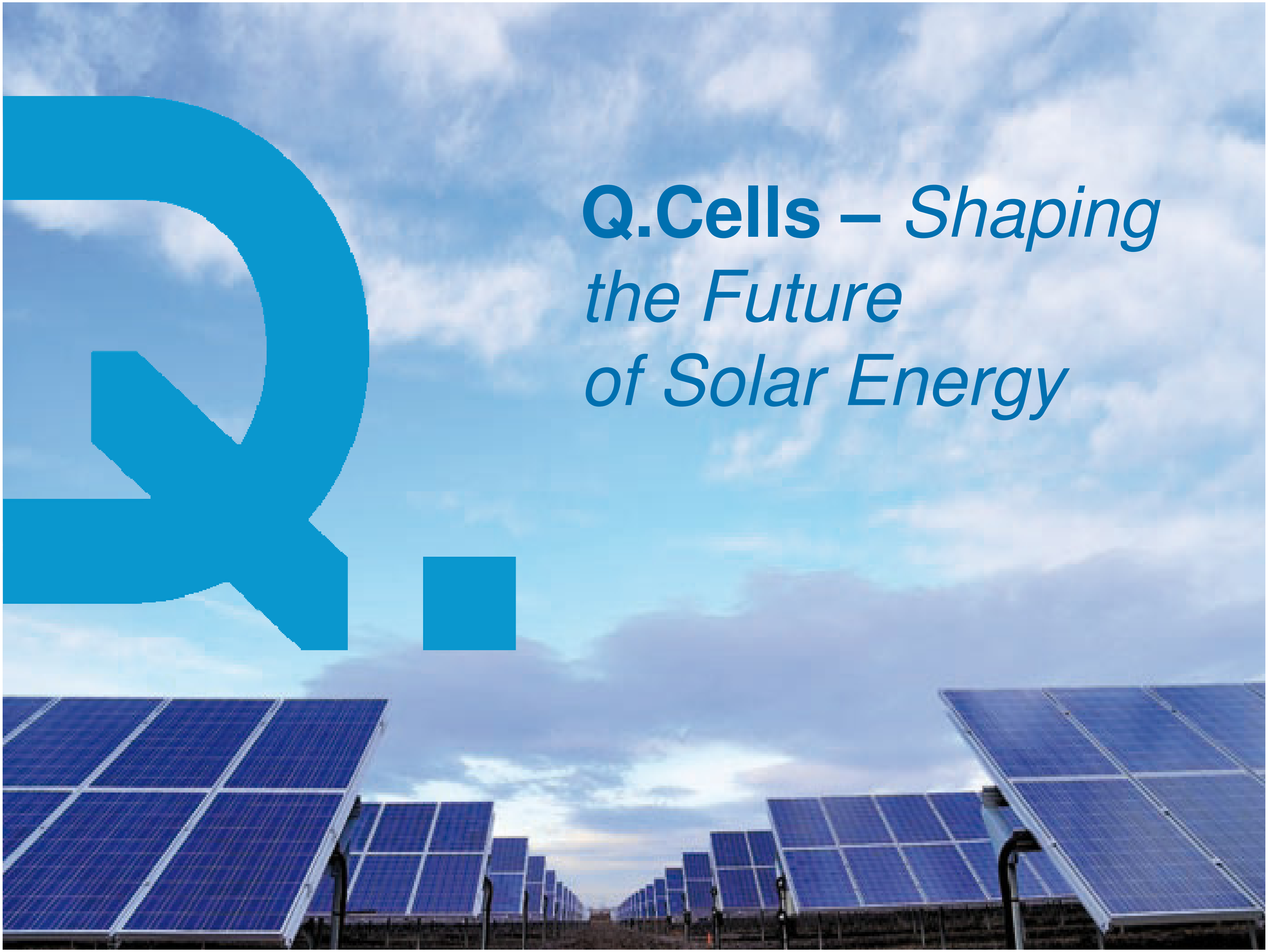
OUTLOOK ...



MASSIVE INVESTMENT INTO RENEWABLE ENERGIES AND ESPECIALLY IN PV IS MANDATORY FROM AN ECONOMIC AND ENVIRONMENTAL PERSPECTIVE

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

Courtesy Eicke Weber: 25th EU-PVSEC&WCPEC-5, Valencia, September 7, 2010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