
Solar Vision - Rethinking Renewable Energy Targets

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Fraunhofer-Institute for Solar Energy Systems ISE

Director:
Prof. Eicke R. Weber
Founded: 1981
Budget: 44.2 Mio EUR ('07)
Staff: ca. 750 (total)



Why do we need to transform the global energy system?

- Protect the basis of human life on earth from the catastrophic consequences of climate change
- Limited availability of non-renewable energies
- Reduction of geopolitical conflict potential

Strategies to reduce use of fossil fuels and CO₂ emission

- **Energy efficiency** - in production, traffic, building sector
- **Nuclear energy** - non-renewable supply, final storage not clear, dangers during operation: no good solution for the global energy problem
- **Clean coal technologies** - requires carbon sequestration, unproven technology, energy inefficient, may create danger of accidental release
- **Geothermal** - reliable, efficient, but good sites are limited
- **Wind** - good, but fluctuating production, limited number of suitable sites
- **Hydro** - can be switched on instantaneously, suitable for storage, Good sites limited, production should be maximized
- **Biofuels** - interesting as liquid fuel for traffic, production energy intensive
- **Solar energy** (Photovoltaic, Solarthermal) - unlimited energy source
PV: continuous price reduction through savings of scale

Magnitude of Solar Energy

- Each hour the sun delivers to earth the amount of energy used by humans in a whole year
- Sun radiation onto earth corresponds to 120,000 TW
- Total human energy need in 2020: 20TW!

Source: G.W. Crabtree and N.S. Lewis, Physics Today, March 2007

Solar energy
is the only kind of energy that can solve the
earth's energy problems!

Al Gore on July 17, 2008: In 10 years 100% of electricity from RE!

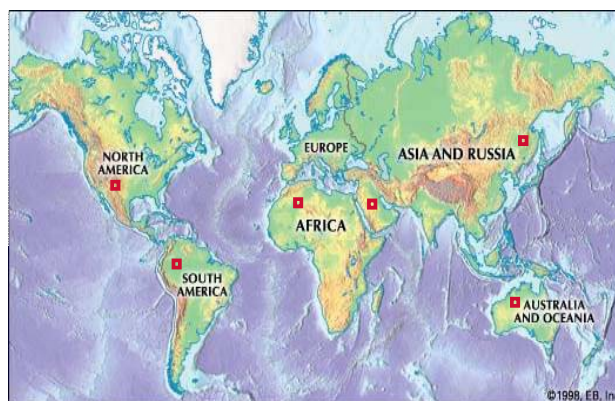
Required Area for PV

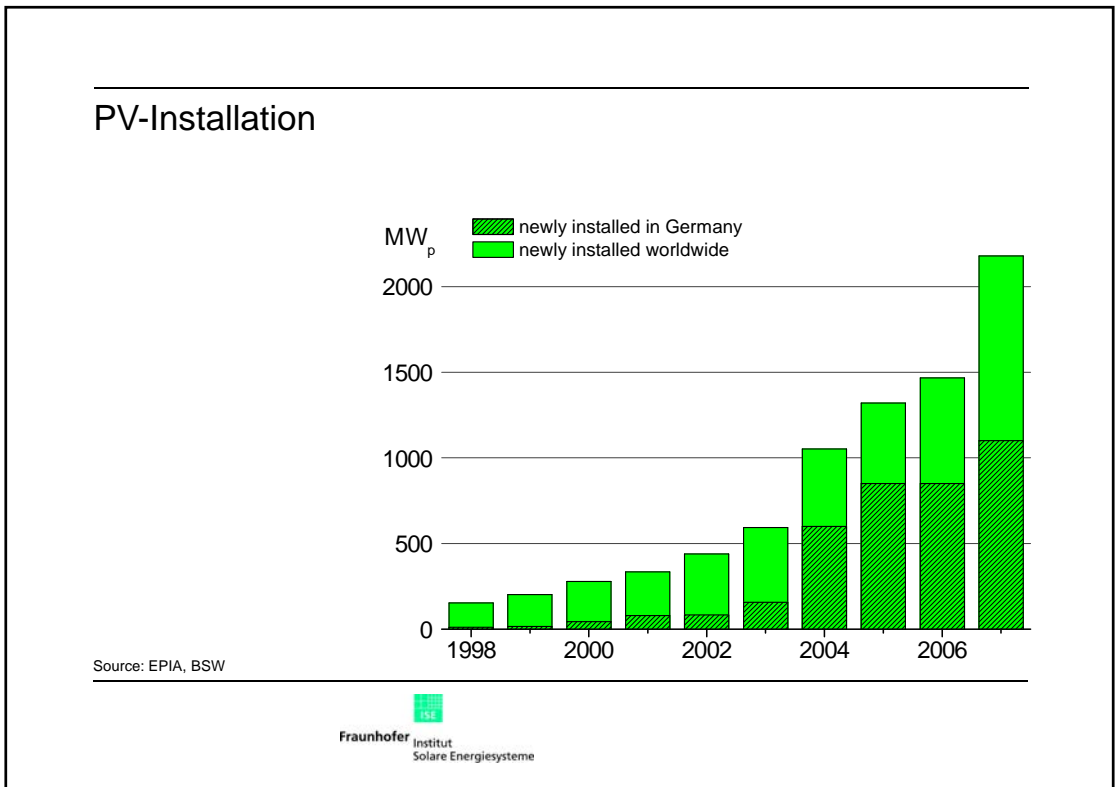
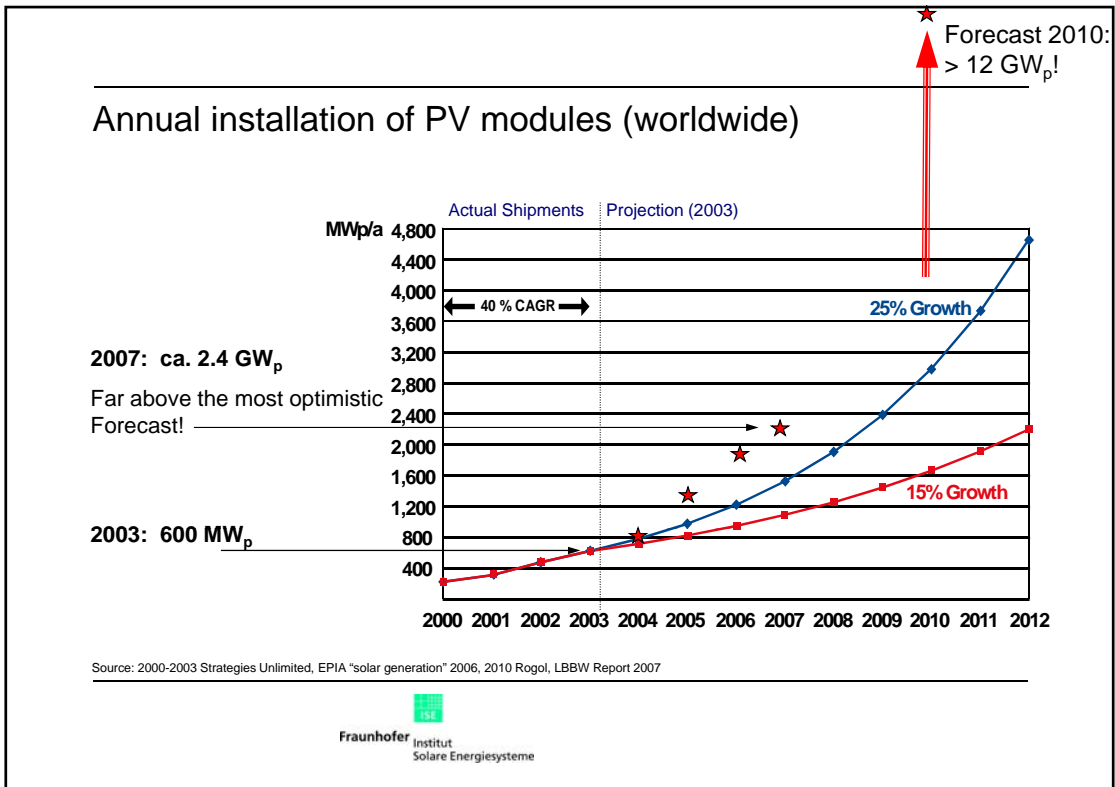
Area required to produce 20 TW through PV:

6 sites, 340 x 340 km² each producing 3.3 TW

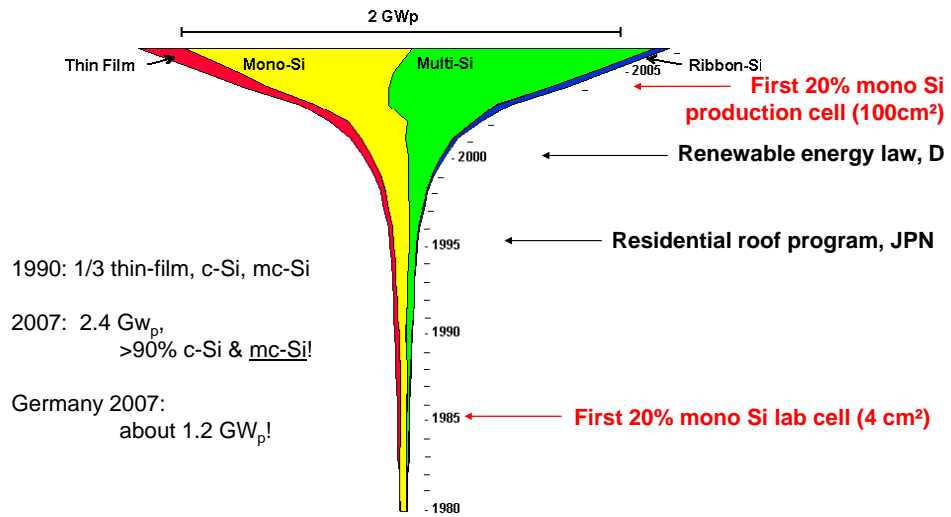
(using 15% PV cells, 1600hrs/a of sunshine)

PV can easily supply a substantial part of the world energy needs



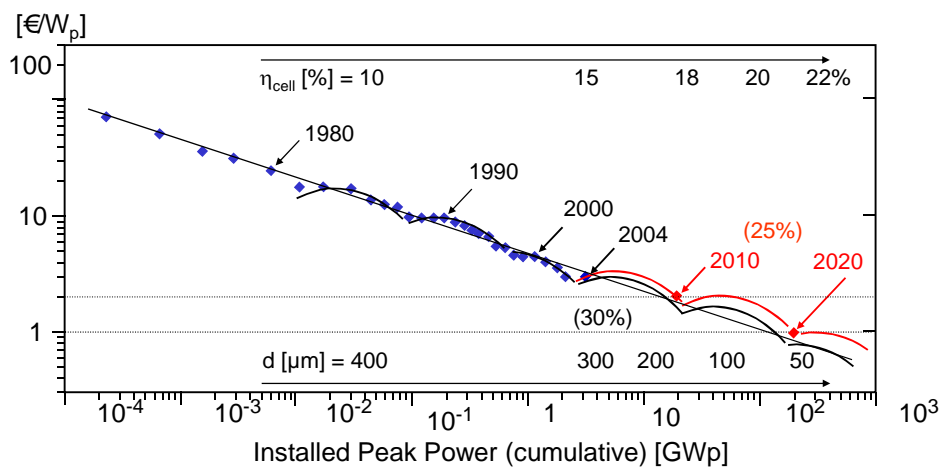


Development of the global PV-market



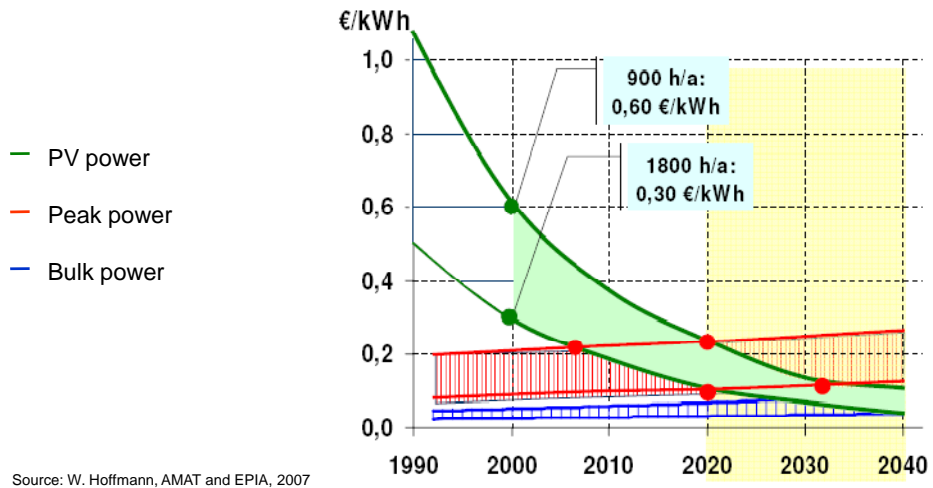
Graph: G. Willeke, 2008

Price learn curve of crystalline Si PV-modules



Graph: G. Willeke, ISE

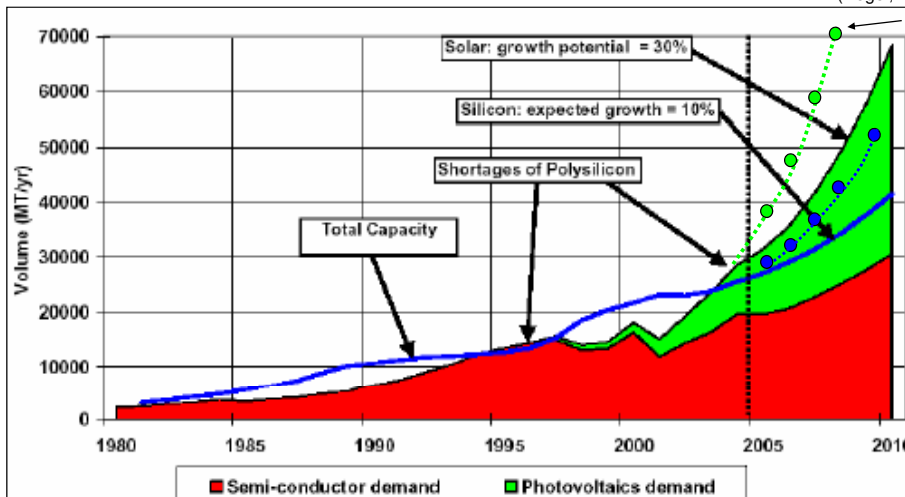
Competitiveness of PV power and utility prices



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The Problem of the Si feedstock shortage

Forecast April 2007
(Rogol, Munich 07)



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September 24, 2008

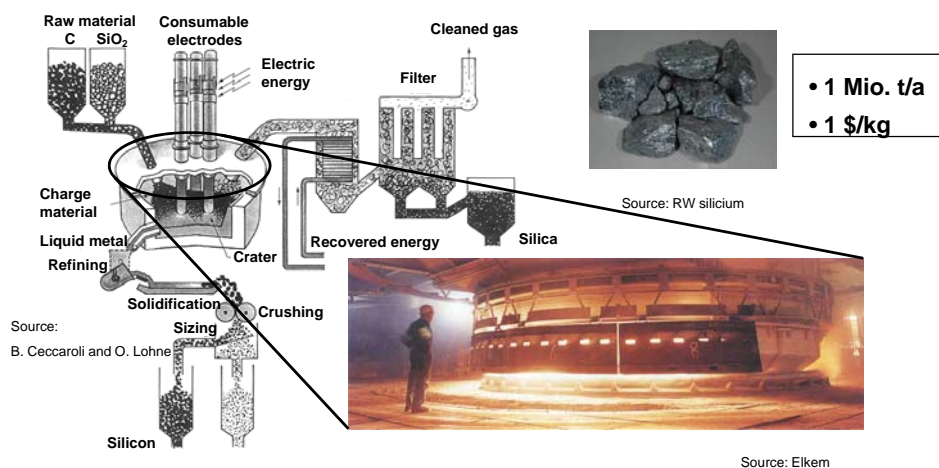
CallSolar Confidential

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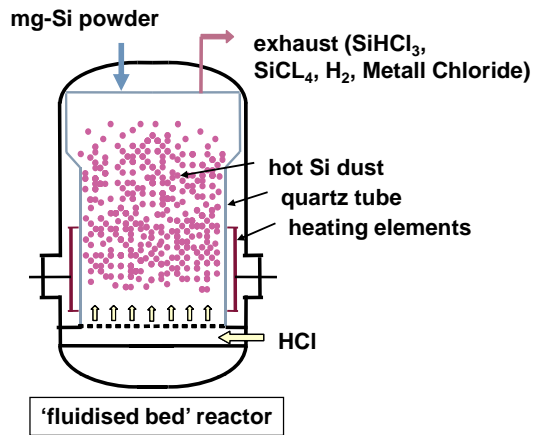
Possible solutions of the Si feedstock shortage:

- Increased production of semiconductor-grade Si: for 2010, > 70 kt/a expected;
- Thinner cells (but: limits cell size!);
- Thin film cells, such as a-Si, CIS, CIGS, CdTe (but: limited efficiency, >10% difficult!)
- Thin-film c-Si cells on various substrates (of special interest: metall. grade mc-Si!);
- Upgraded metallurgical-grade Si („dirty Si“)
- Highly efficient cells for concentrators

From quartz to coal to metallurgical Silicon (mg-Si)



From mg-Si to ultrapure poly-Si: the Siemens Process



ca. 30.000 t/a
ca. \$100/kg

fractional distillation

Alternative for PV: upgraded metallurgical Si, umg-Si ('dirty silicon')

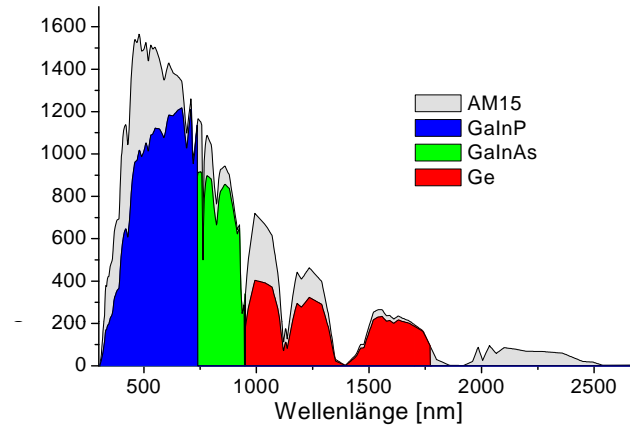
Advantages of umg-Si in comparison with Si purified in the gasphase:

- Lower costs of investment (Siemens process: ca. \$100M for 1000t/a)
- Lower price (production costs: ca. \$10/kg)
- Lower energy consumption (Elkem: 1/10 Siemens Proc)
- Faster growth of production volume possible (100.000t by 2010?)

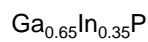
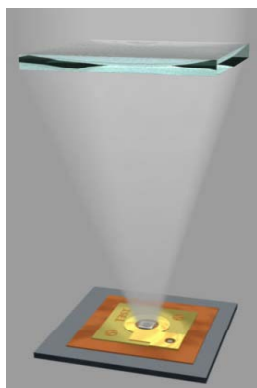
Efficiencies beyond the Shockley-Queisser limit

Maximum efficiencies
(theoretical, without optical concentration):

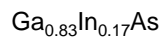
- ⇒ 2-jct. cells: 45.3%
- ⇒ 3-jct. cells: 51.2%
- ⇒ 4-jct. cells: 54.9%
- ...



High-efficiency ISE triple-junction solar cells



tunnel diode



tunnel diode

Ge substrate



Triple-junction solar cell for high optical concentration, η ca. 40%

GaInP/GaInAs/Ge
solar cell with
 $\eta = 39,7 \%$
at $C = 350$



High-concentration PV tracker systems



Solar Systems (AUS)

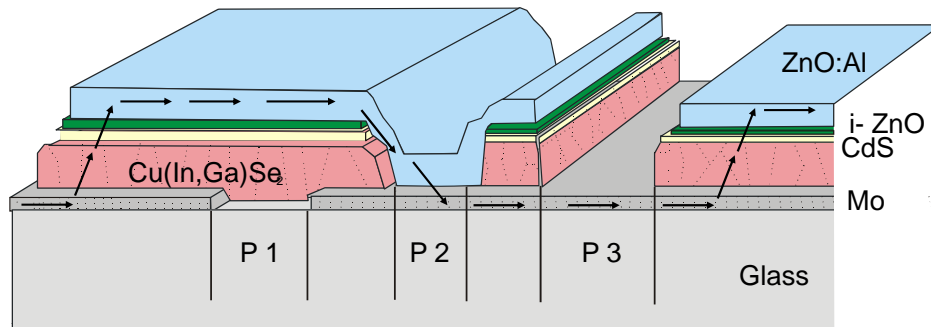


Amonix (US)



Concentrix Solar (D)
(ISE spin-off)

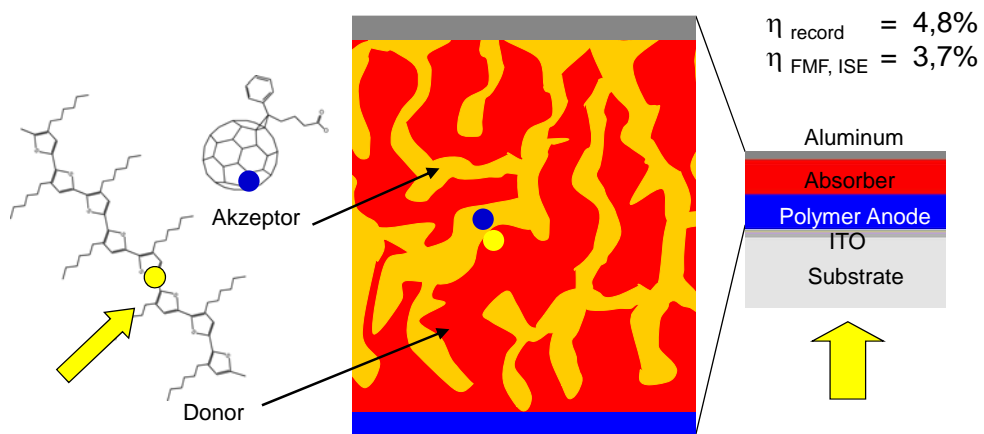
CI(G)S – Solar Cell, schematic



Record efficiency: 18% (small area)
Best module efficiency: ca. 11%

Source: ZSW (Stuttgart)

Organic Solar Cell



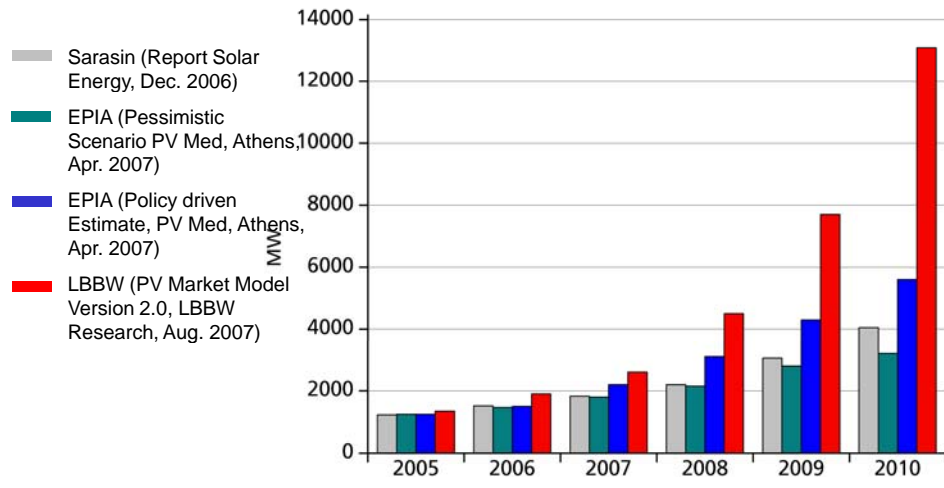
Conclusion I: the big picture for solar energy

- ◆ PV will grow in the coming decades 10 - 100 times in volume, from a \$15 B market into a \$100 - 300 B market, replacing fossil fuels, reducing climate gases, and providing energy for the world, including developing countries such as China and India.
- ◆ PV provides valuable peak power, today it is already economically competitive in certain areas; lower cost of PV and rising cost of oil and other fossil fuels will result in grid parity in the near future
- ◆ Crystalline Si will remain the dominant PV technology for a long time, the current shortage will be overcome by increased production of pure Si and the introduction of purified (upgraded) metallurgical-grade Si.
- ◆ Crystalline Si offers any amount of PV power without any resource limitation, i.e. it is truly sustainable even in a 100s of GW_p/a market.

Conclusion II: the big picture for solar energy

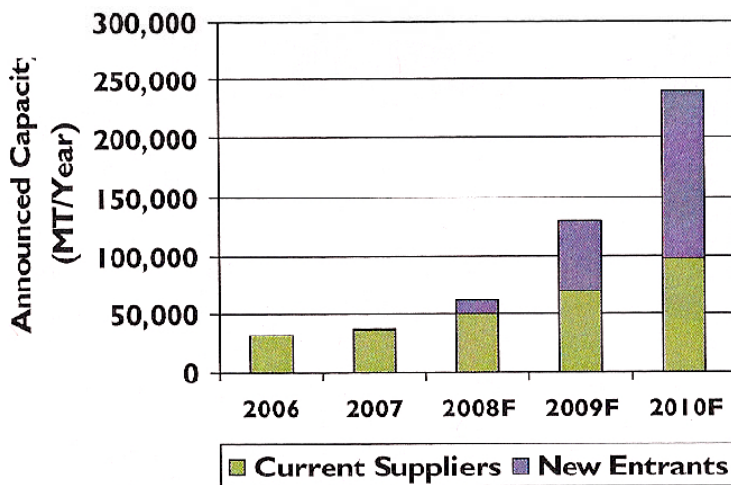
- ◆ Thin film modules out of a-Si, CIS, or CdTe have an interesting market opportunity today, their long-term success will depend on efficiency improvements and cost reduction.
- ◆ Organic solar cells, other '3rd generation' concepts will serve interesting market niches, but are not likely to affect the global picture.
- ◆ One key to decreasing costs for PV is the production volume; therefore intelligent support mechanisms such as intelligent feed-in laws are required worldwide for the next 10-15 years.
- ◆ A second key to decreasing costs for PV and large volume production is the use of alternative Si with higher impurity content: 'Dirty Silicon' - umg-Si
- ◆ EPIA promise: European PV industry is prepared to provide 12% of Europe's electricity needs from PV by 2020! (with effective political support)

Weltweiter PV Markt, Prognosen



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Polysilicon Capacity Trends: *How will new entrants fair?*



Includes captive and merchant markets; solar and semiconductor applications.

Source: SEMI, June 2008