Solar PV Technology Trends

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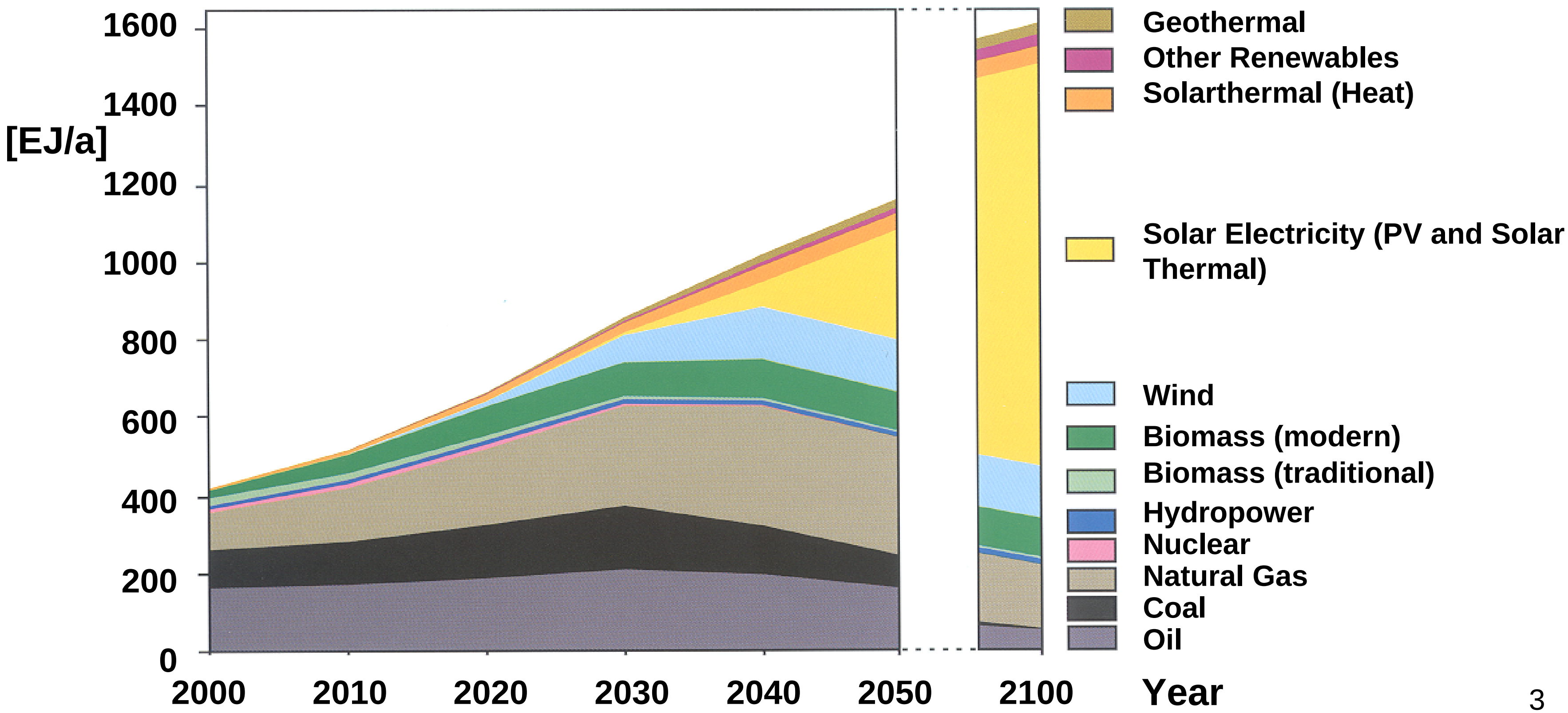
Overview

- **Motivation**
- **The Question of Resources and Market Growth**
- **Crystalline Silicon Solar Cells and their Potential**
- **High Concentration PV: an Emerging Technology**
- **Outlook**

Global Primary Energy Scenario (WBGU 2003)

Scientific Advisory Committee WBGU of the German Government



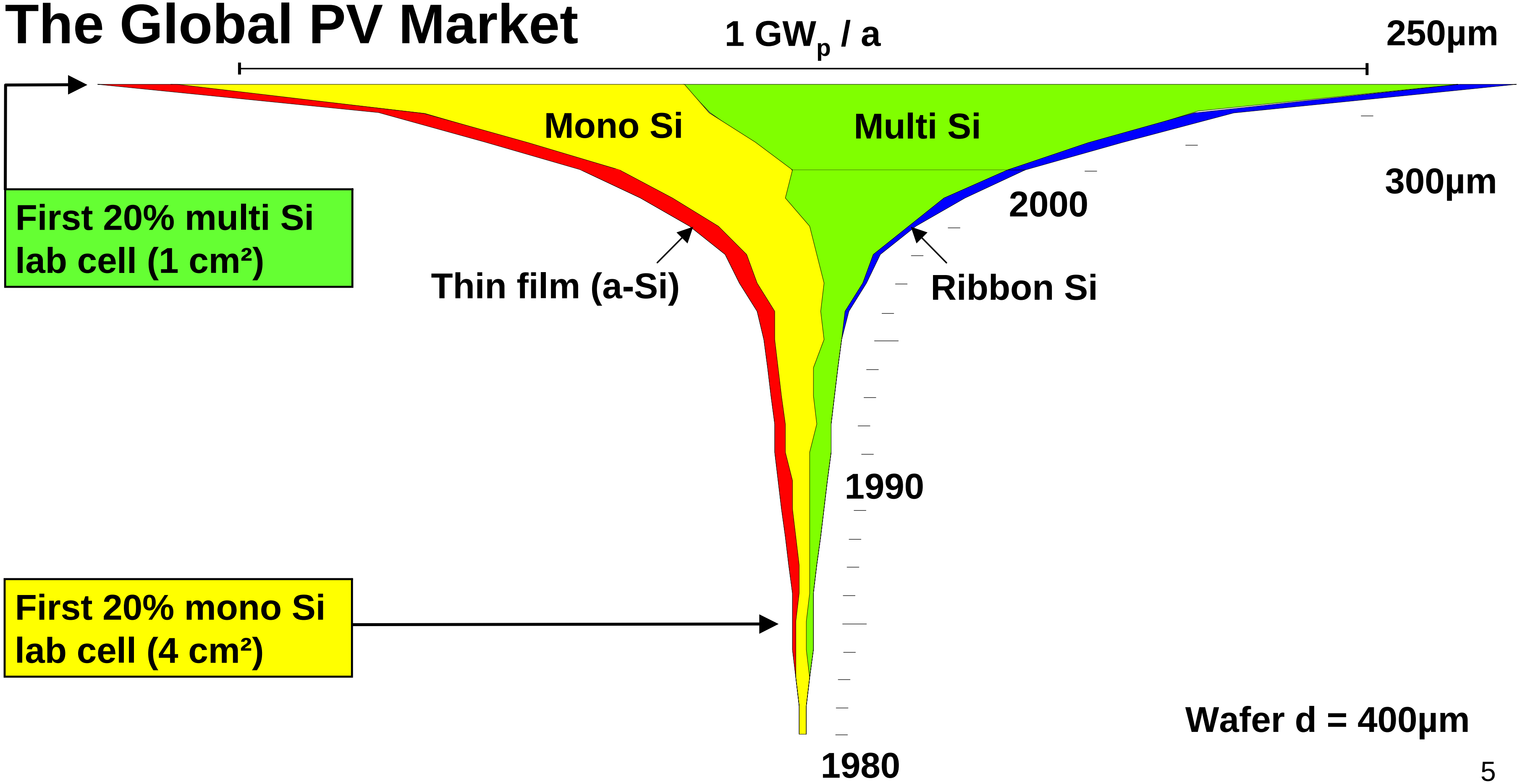
A Question of Resources

	World Production [1000 t/a]	Reserve Base* [1000 t]	d [µm]	150 MW_p/a (2000) Feedstock [1 000 t/a]	150 GW_p/a (2030) Feedstock [1 000 t/a]
Si (c-Si)	1 000	abundant	300 ⇒ 100	3	1 000
Si (a-Si)			3	0.030	30
Te (CdTe)	0.1	47	3	0.078	78
In ($CuInGaSe_2$)	0.3	6	3	0.078	78

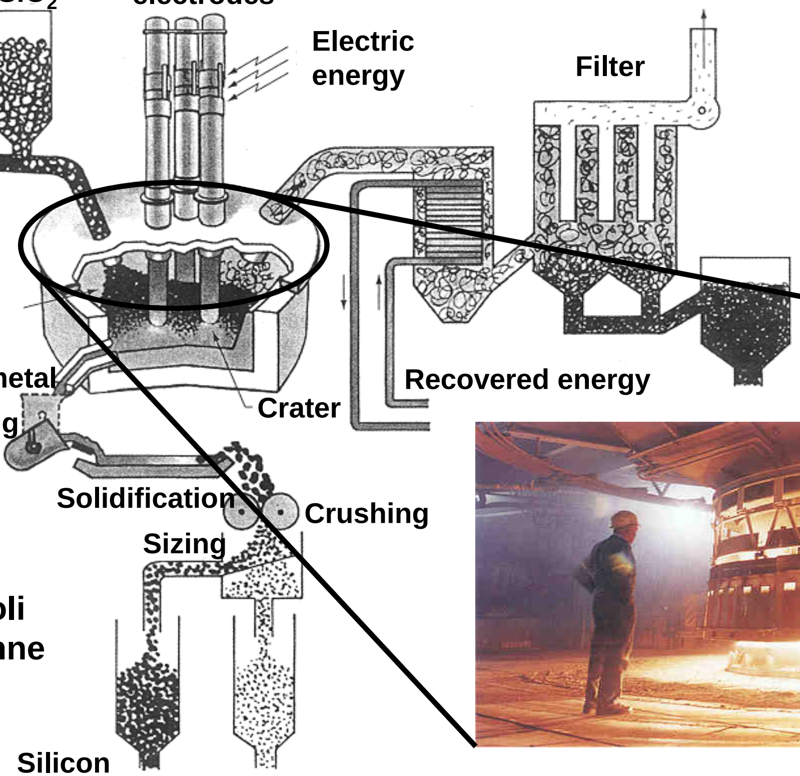
* Resources that are currently economic, marginally economic and some of those that are currently subeconomic

Source: US Geological Survey 2005 [http://minerals.usgs.gov/minerals/pubs/commodity/]

The Global PV Market



From Quartzite Rock and Coal to Silicon Metal

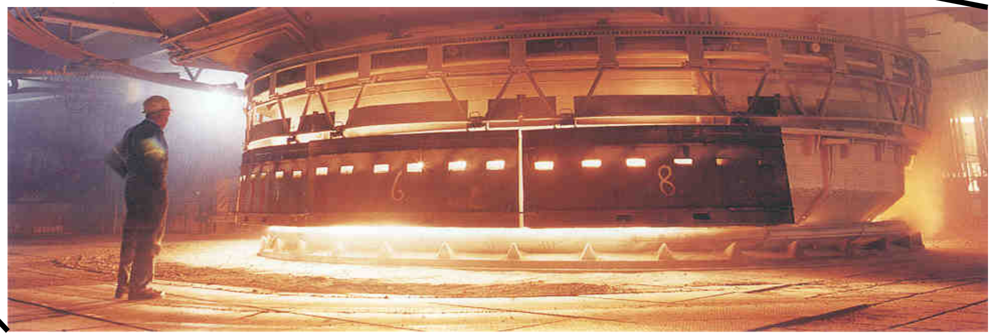


1 000 000 t/a

$$Si(s) + 3HCl(g) \rightarrow SiHCl_3(g) + H_2(g)$$

Purification via fractioned distillation

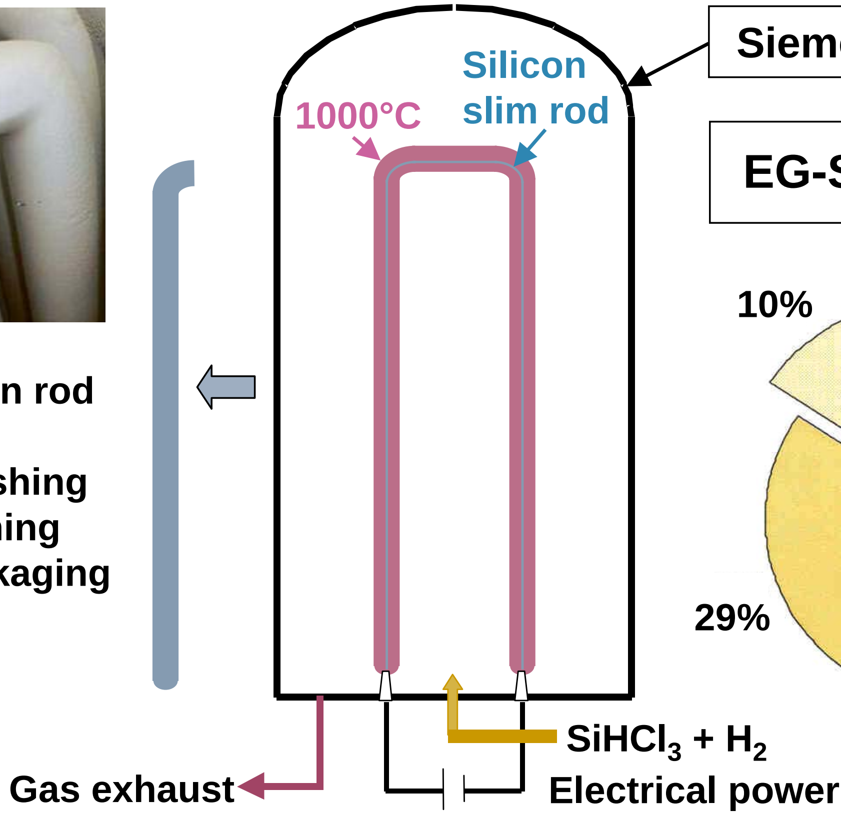
Source:
B. Ceccaroli
and O. Lohne



Source: Elkem

From Highly Purified $SiHCl_3$ to Solar Silicon (Siemens)

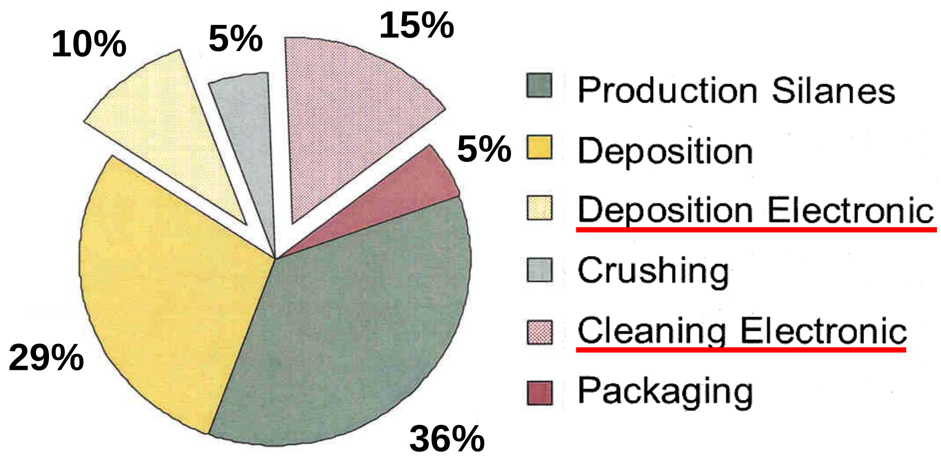
Silicon rod to
- **Crushing**
- **Etching**
- **Packaging**



Siemens Reactor

27 000 t/a

EG-Si: 40 $/kg → SOG-Si: 30 $/kg

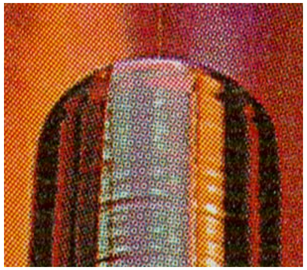


Source: Dr. K. Hesse, Wacker Polysilicon

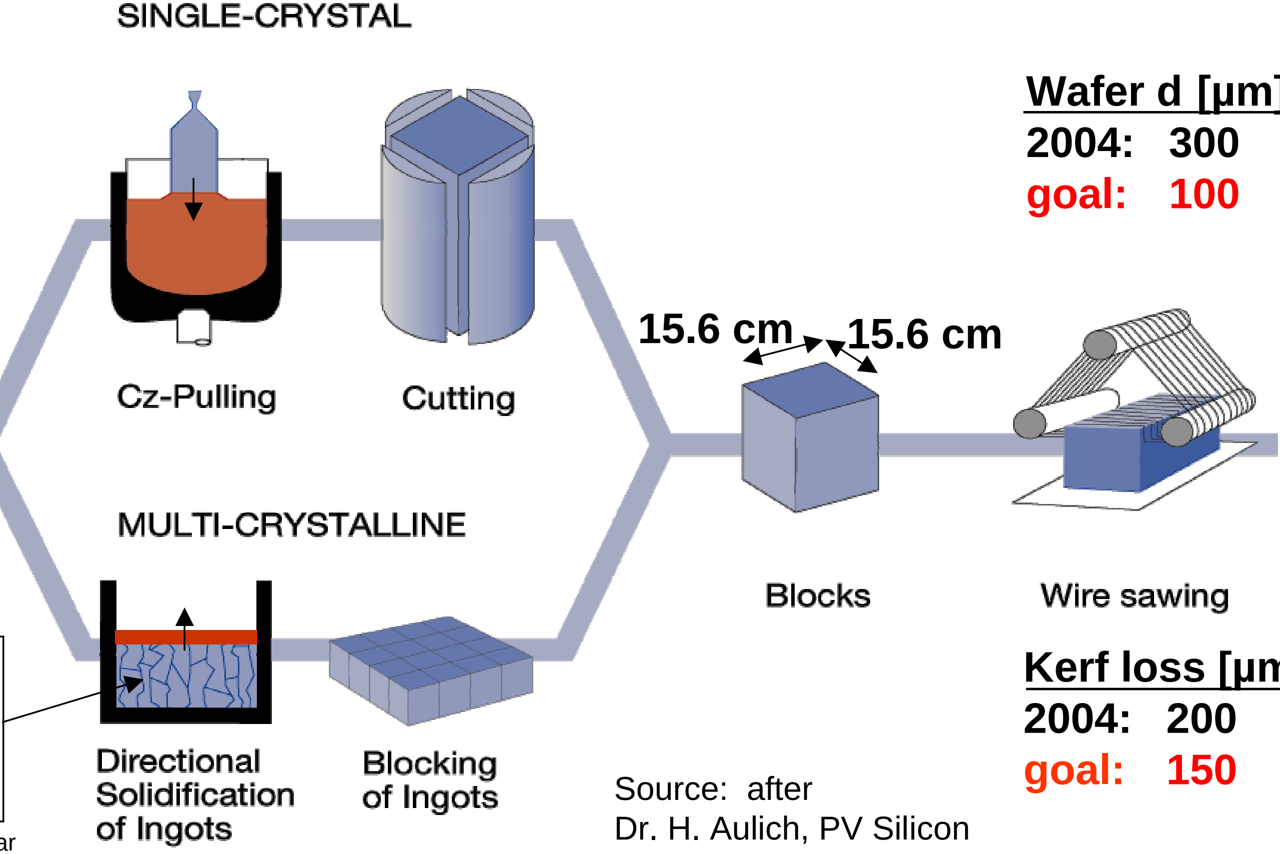
From Highly Purified $SiHCl_3$ to Solar Silicon (Fluid Bed)

Source: after Dr. K. Hesse, Wacker Polysilicon

From Solar Silicon Feedstock to Solar Silicon Wafers



Photon Special 05/06



Wafer d [µm]
2004: 300
goal: 100

1995: 150 kg
2004: 330 kg
2008: 1000 kg

Dr. A. Müller, Deutsche Solar

Kerf loss [µm]
2004: 200
goal: 150

Source: after
Dr. H. Aulich, PV Silicon

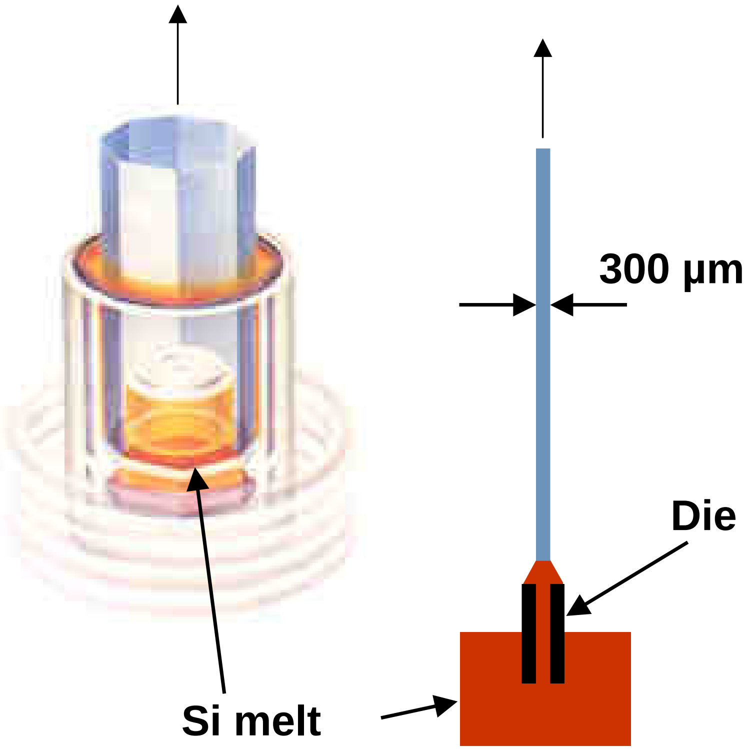
Ultrathin Wire-Saw Wafering

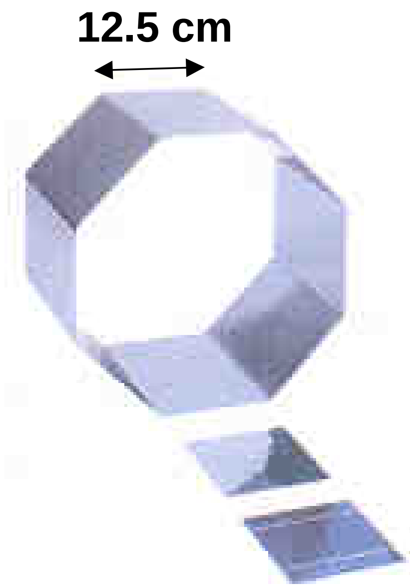
100 µm thin,

flexible Wafer

Source: Dr. H. Aulich, PV Silicon

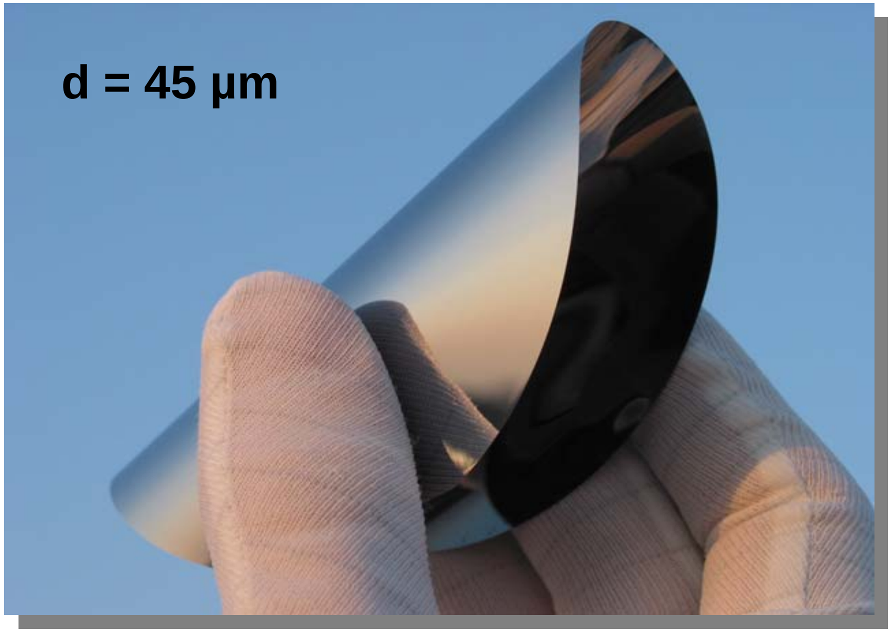
Ribbon Silicon: Edge-defined Film-fed Growth EFG





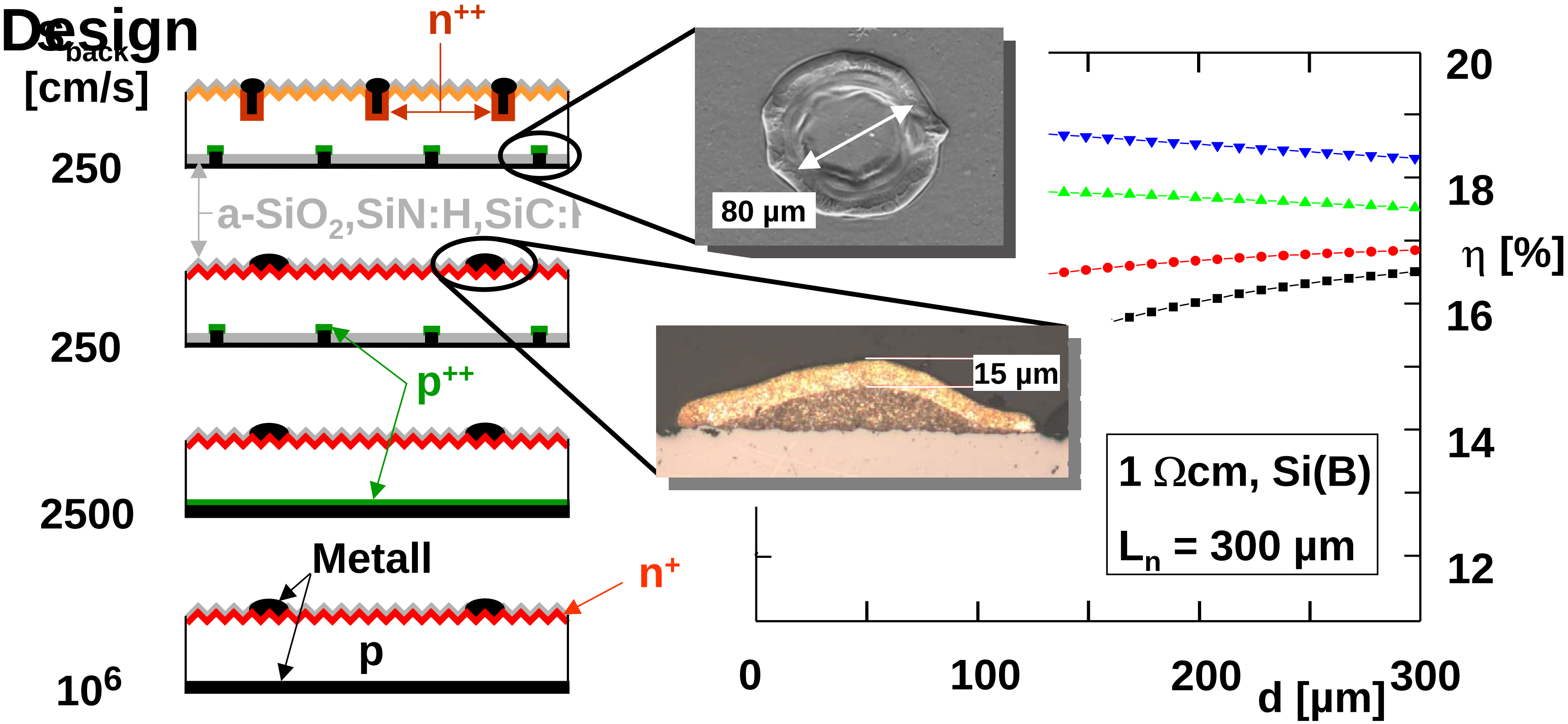
Source: after
Dr. W. Hoffmann, RWE Schott Solar

Ultrathin Crystalline Silicon Solar Cells (I)



Source: K.-U. Vayhinger, Manz Automation

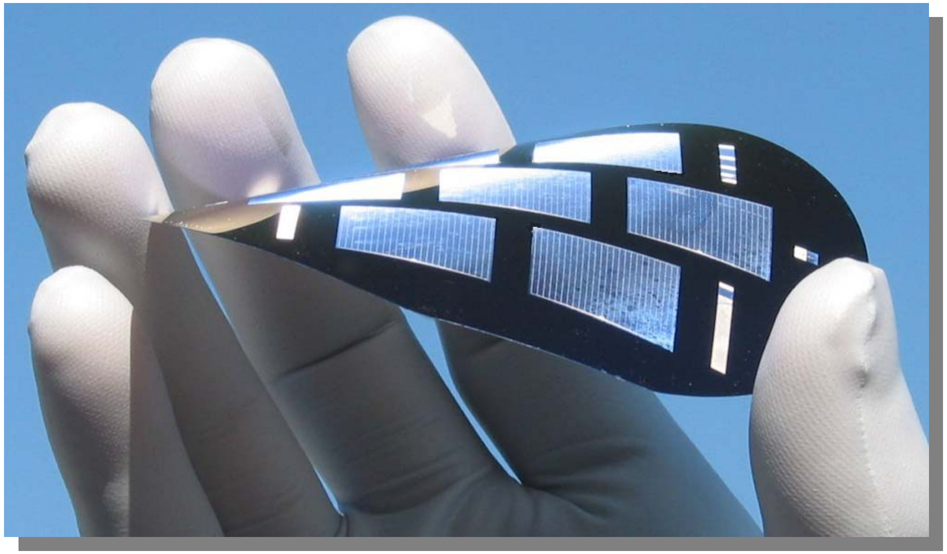
Simulation: Thickness Dependence Cell Efficiency / Design



Source: after S. Glunz

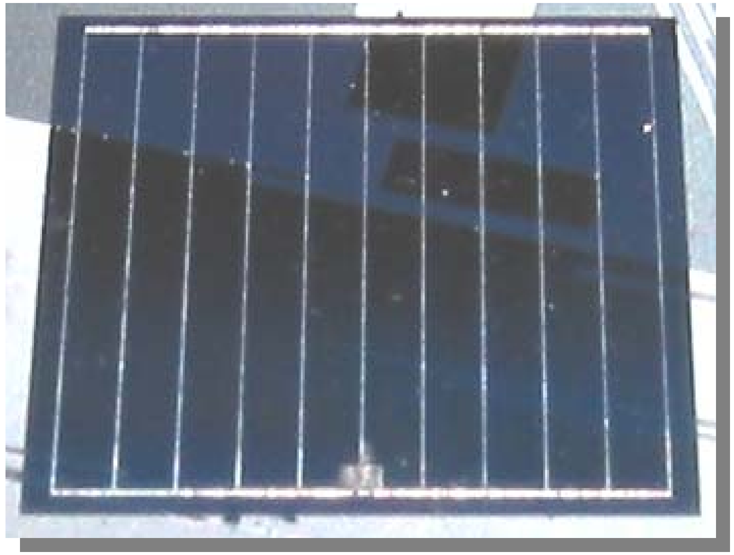
Ultrathin Crystalline Silicon Solar Cells (II)

d = 37 µm, η = 20.2 %, A = 4 cm²



Monocrystalline Silicon

d = 99 µm, η = 20.3 %, A = 1 cm²



Multicrystalline Silicon

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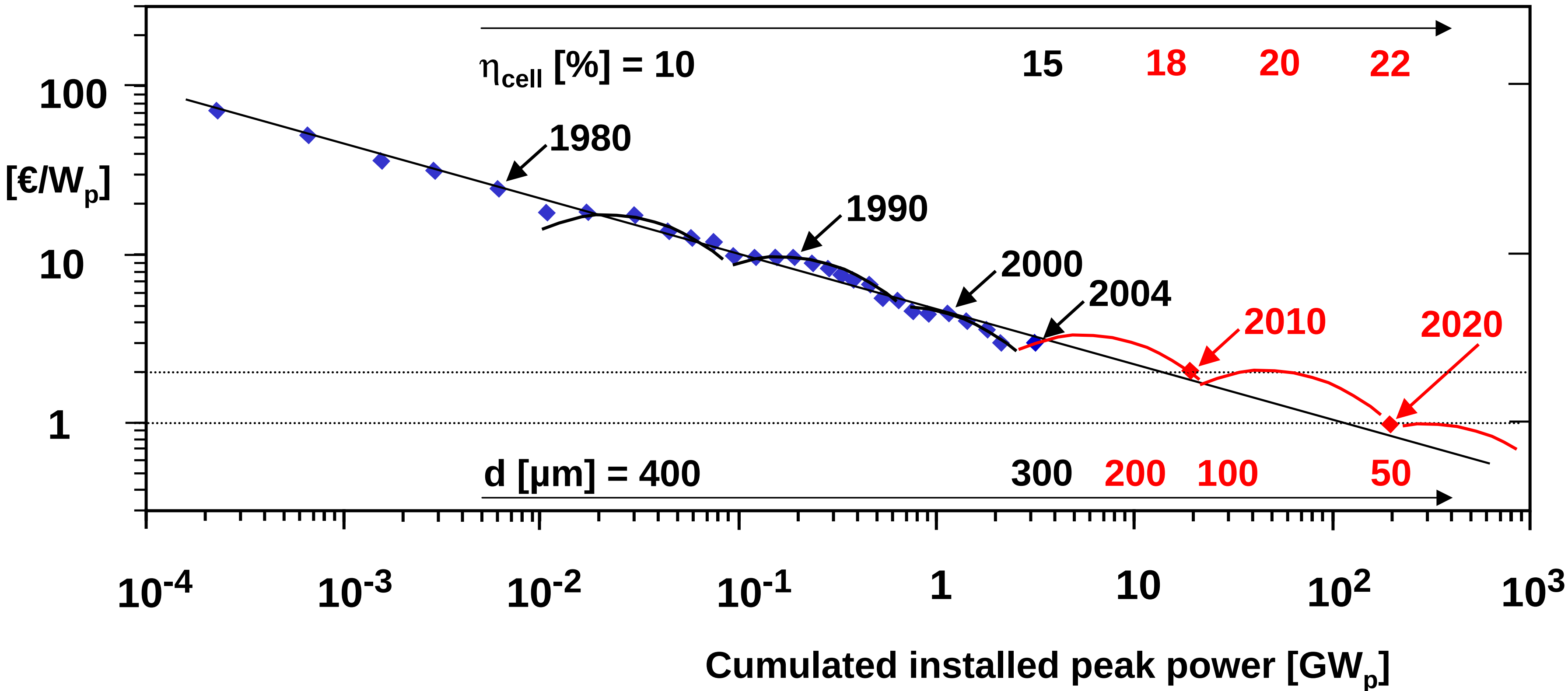
Price Experience Curve for Crystalline Si Modules (25%/a)



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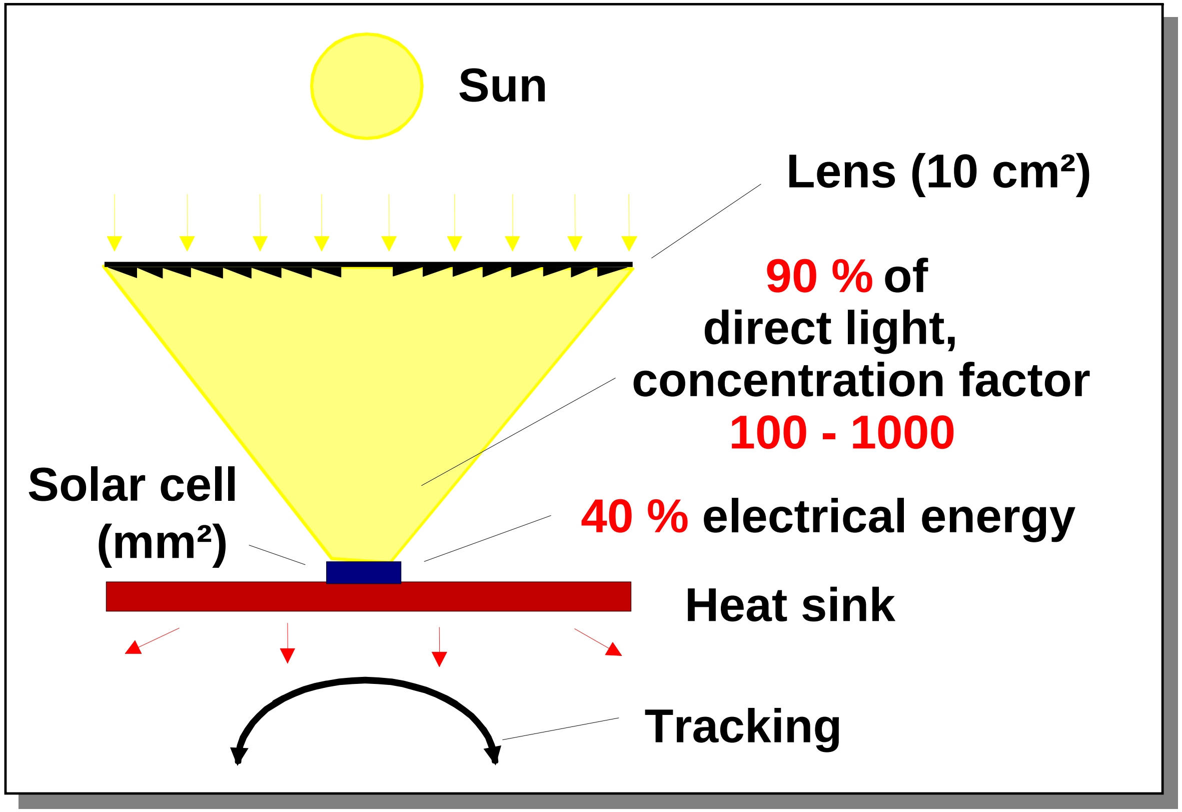
Motivation Concentrator Technology

Idea:

Replace valuable semiconductor material by inexpensive optics and mechanics

Multijunction cells
$+\ \eta$**(T=const) ~ ln(c)** $\Rightarrow$
system efficiency up to 30 %

Tracking $\Rightarrow$
more kWh per kWp



Source: after A. Bett

FLATCON™ Technology for Concentrator Generators

Fresnel Lens All-glass Tripel junction CONcentrators

Source: H. Lerchenmüller (Concentrix Solar GmbH)

Outlook

- **PV system prices with crystalline silicon wafer technology in 2020:**

  2 €/W_p ⇒

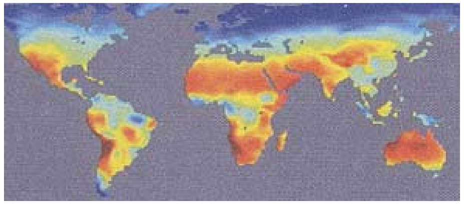
  Grid-connected electricity price:

  17 €cents/kWh ⇒

  Silicon PV electricity is economical in D

- **System prices of 1 €/W_p are conceivable with crystalline Si wafer technology**

- **High concentration PV is a competitive emerging technology for regions with direct insolation**



Source: G. Czisch, ISET