

Dutch Solar Energy R&D Seminar 2009,
13 October 2009, Utrecht



Silicon & Wafer
Solar cell & Module
Thin film module
Semiconductor

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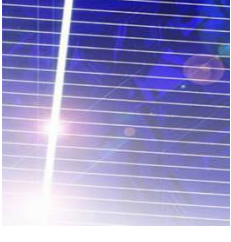
Grid Parity Factory

Disclaimer



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Rounding differences may arise.



Part 1: Current Status

Crystalline Silicon versus Thin Film Technology

- **The Crystalline Si Value Chain**
- **Grid Parity with Crystalline Silicon**

Part 2: Cost Reductions Driven by Technology Advances

Solar Cell Production as an Example

- **Cost of Innovation**
- **Revolution**
- **Evolution**

centrotherm photovoltaics at a glance



- Technology and equipment supplier for PV industry
- Leading market player of turnkey crystalline solar cell production lines
- Unique supplier of turnkey solutions over full crystalline solar cell value chain and leading thin film technology

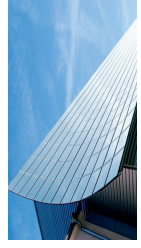
Business Divisions



▶ Silicon / Wafer



▶ Solar cell / Module



▶ Thin film



▶ Semiconductor

Technology & Equipment

Turnkey production plants

Turnkey lines

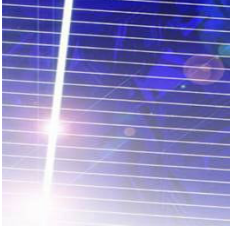
Key equipment

Services

Key Figures

	2007	2008	2009**
Employees:	178	1,050	1200
Sales:	166 M€	375 M€	>500M €
EBIT:	21 M€	56 M€	

* excluding effects from purchase price allocation **estimations for 2009



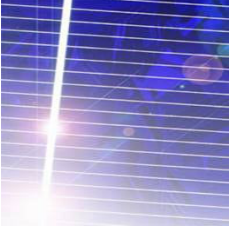
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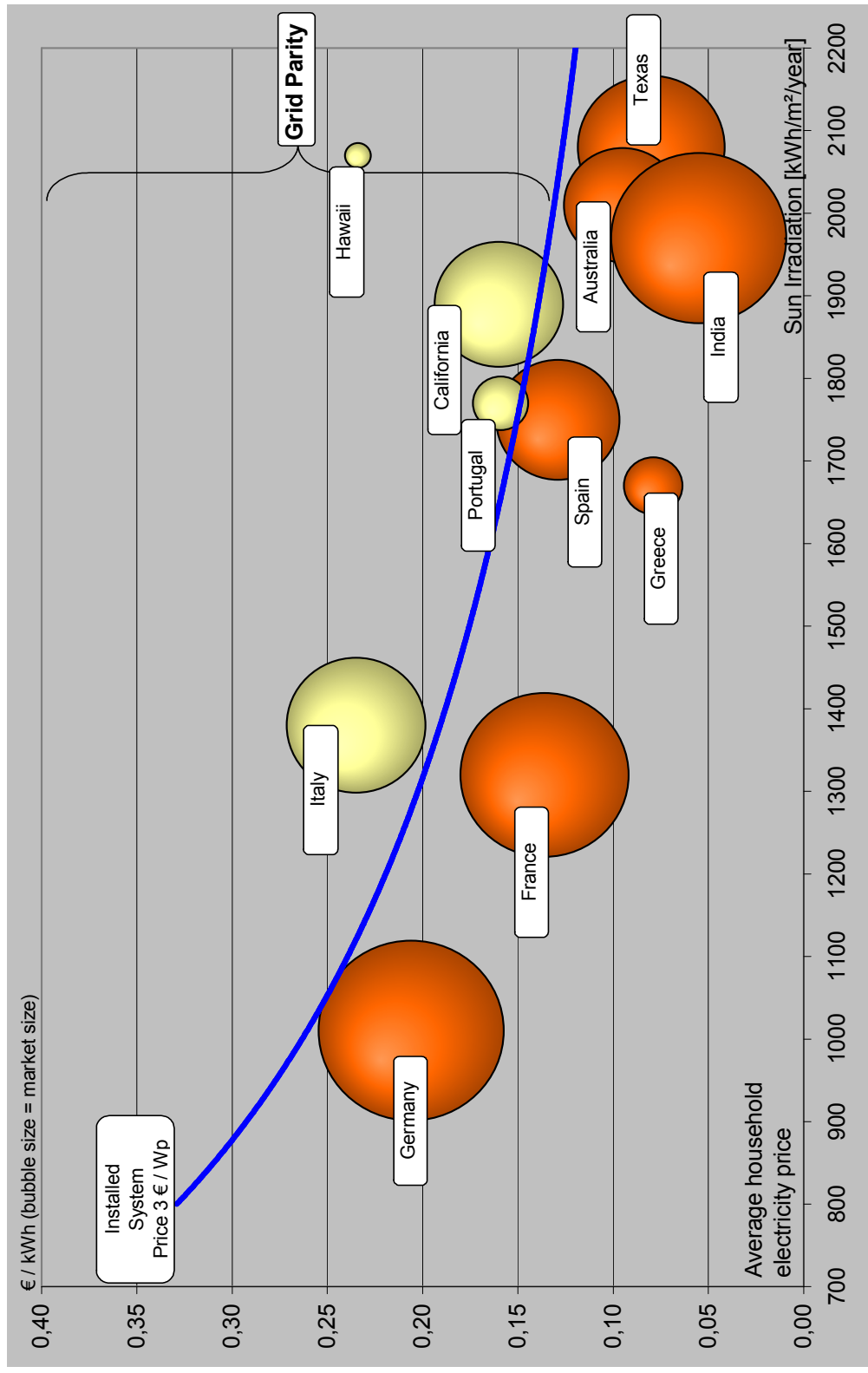
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- Cost of Innovation
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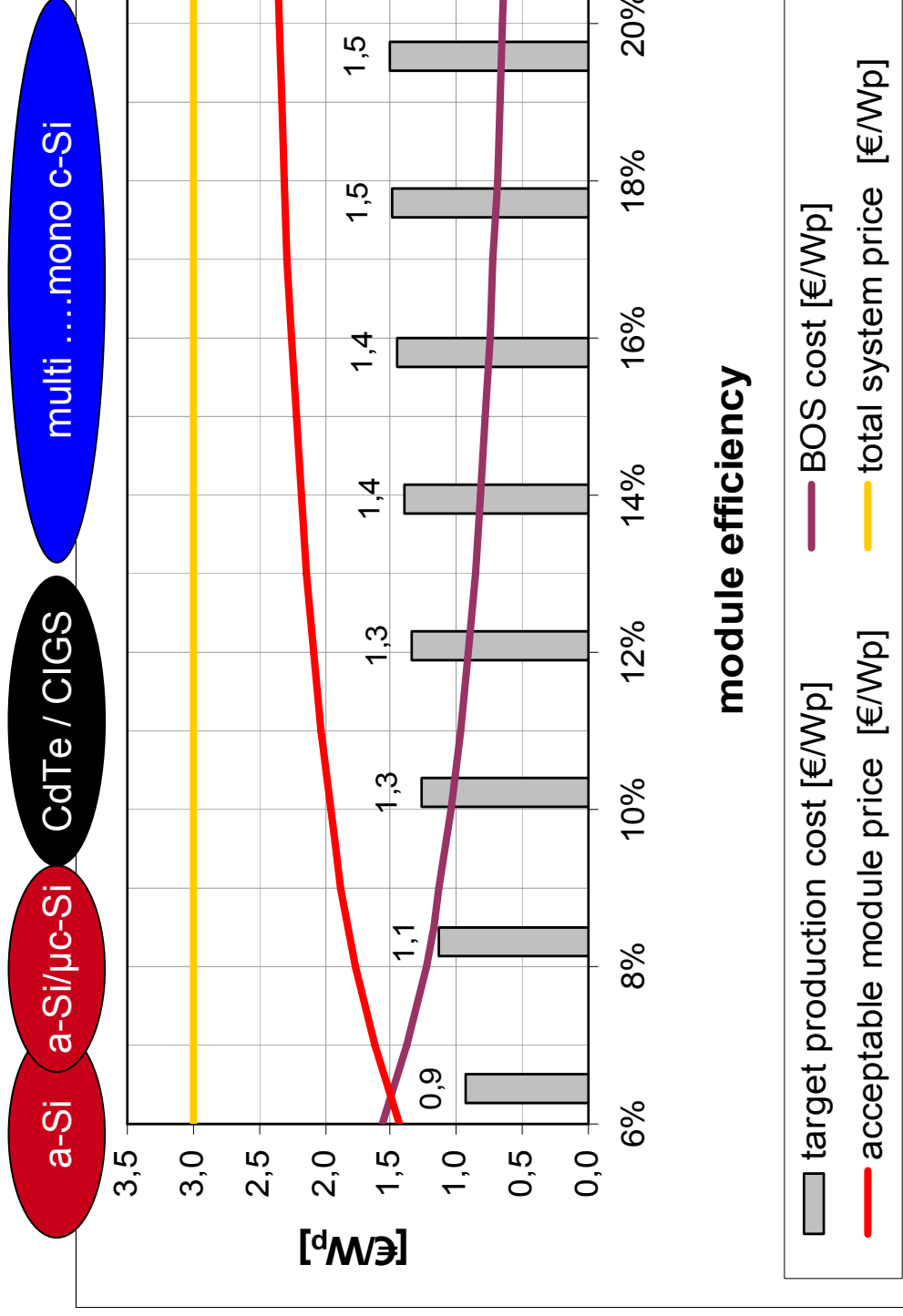


Crystalline Silicon PV versus Thin Film Technology?

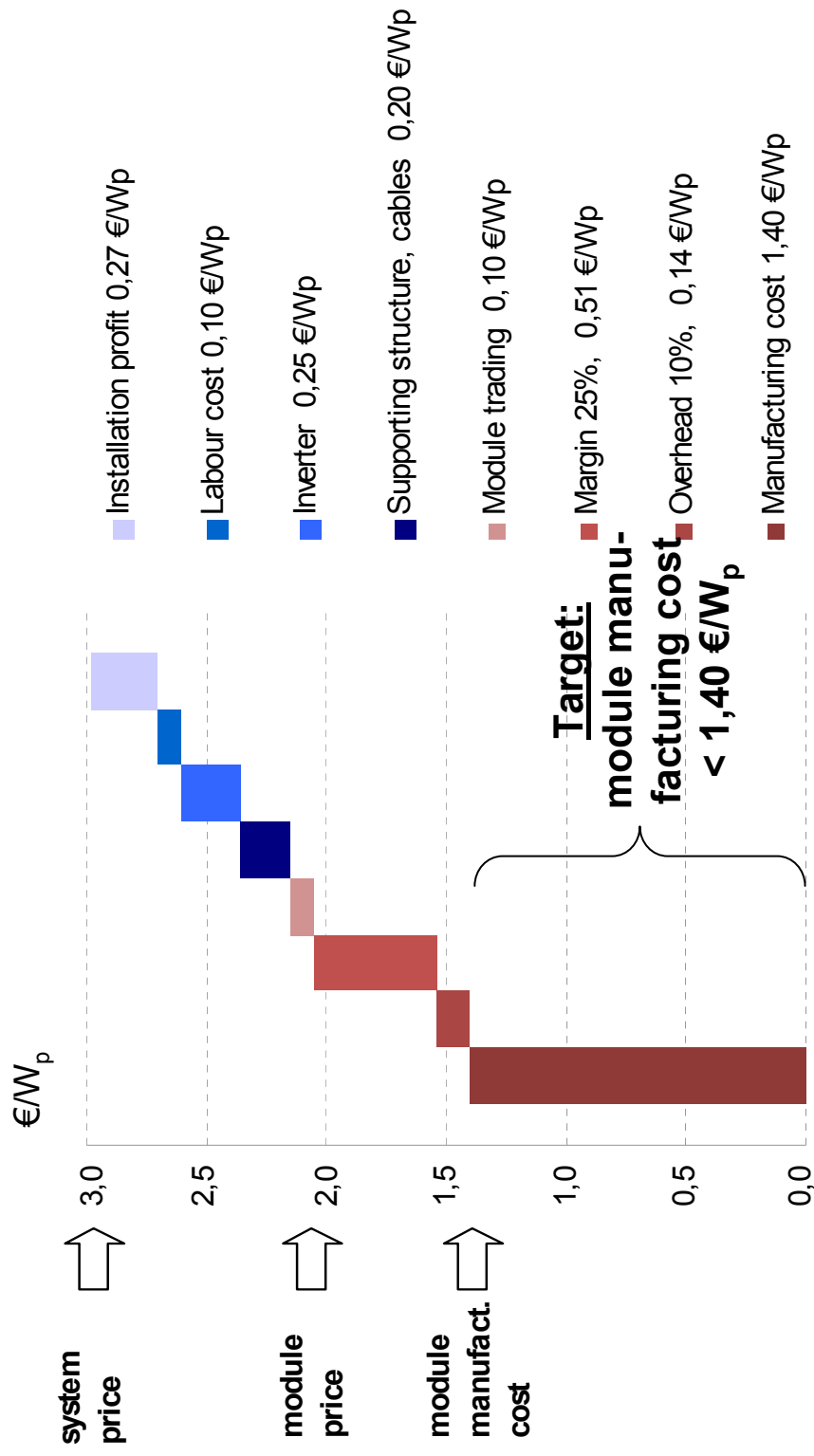
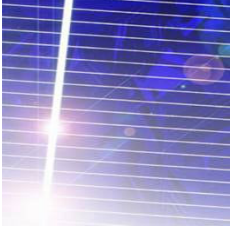
„Customer Retail Price“ Grid Parity @ 3 €/W_p



Balancing Cost, Price and Performance

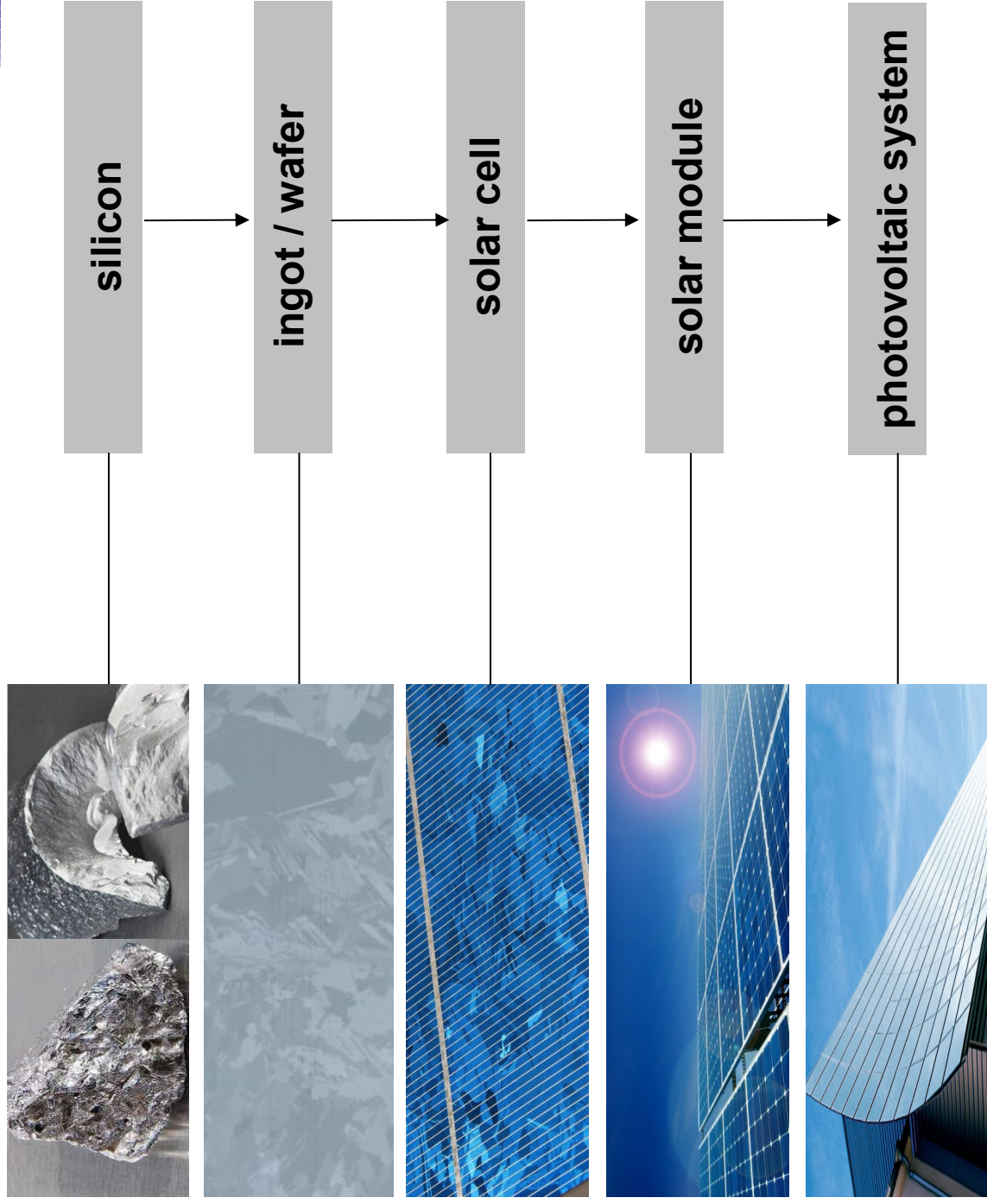
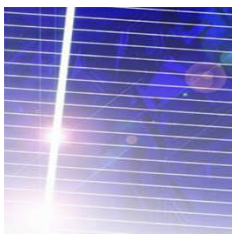


How to Achieve PV System Price < 3 €/W_p?

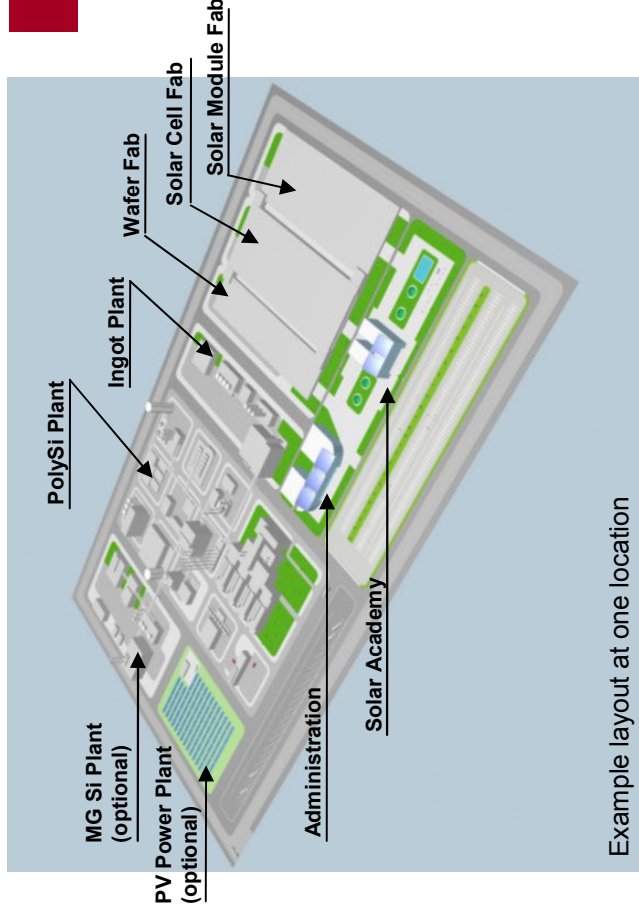


Note: The target module manufacturing depends on the module efficiency. Modules with lower efficiency require lower manufacturing costs („BOS-penalty“). The calculation is based on crystalline silicon with a cell efficiency of 15,8%.

Crystalline Silicon Value Chain



Integrated c-Si Fabrication: Overview

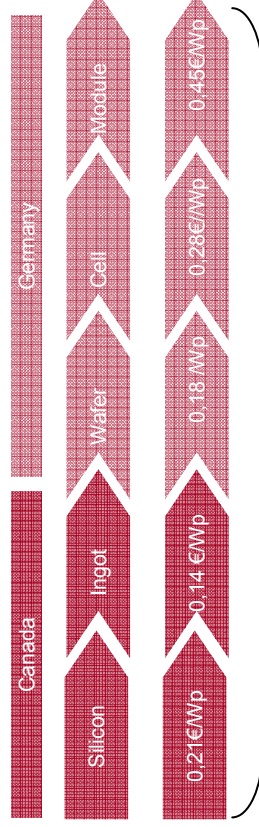


Example layout at one location

Example: Grid Parity factory in Germany/Canada

- Integrated factory consisting of 5 single factories using state of the art technology available today
 - Poly Si (TCS / "Siemens"): 2.500 t/a
 - Multi ingot: 2.270 t/a
 - Multi wafer: 97 million wafer /a
 - Cell: 361 MW_p/a
 - Module: **347 MW_p/a**
- Calculated scenario includes poly silicon factory using lower electricity costs in Canada + wafer, cell & module production in Germany
- CAPEX **718 Mio €** (accuracy +/- 10%)

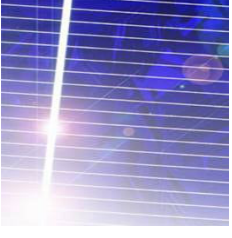
Module manufacturing cost



1,26 €/W_p*

* Accuracy of all figures +/- 10%

Integrated Factory: Various Production Locations



Production costs for three different locations:

- Canada/Germany
- USA
- China

Major differences are the price of electricity and labour.



How to Achieve Grid Parity?



Grid parity can be achieved with crystalline silicon or high efficiency thin film technology.

Target PV system cost: < 3 €/Wp

Option 1:
crystalline silicon technology
(integrated fab)

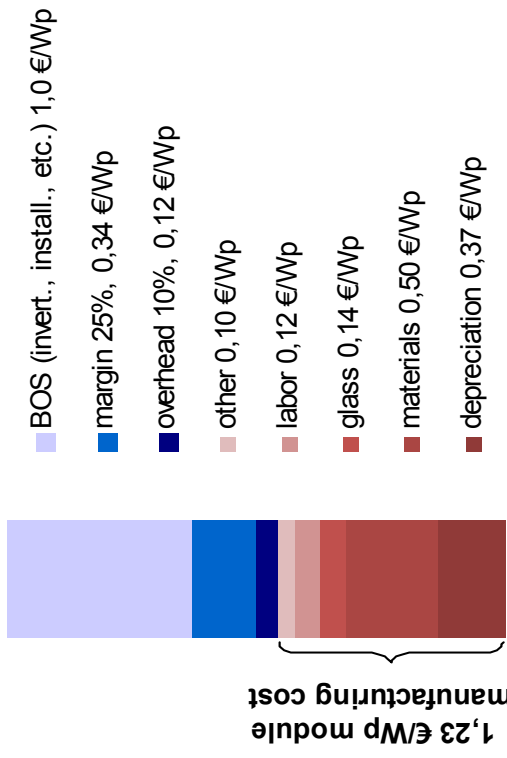
2,6 €/Wp PV system cost



integrated c-Si fab

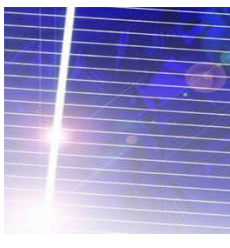
Option 2:
thin film technology
(CIGS fab)

2,7 €/Wp PV system cost



CIGS Thin film fab

Circle for Further Cost Reductions

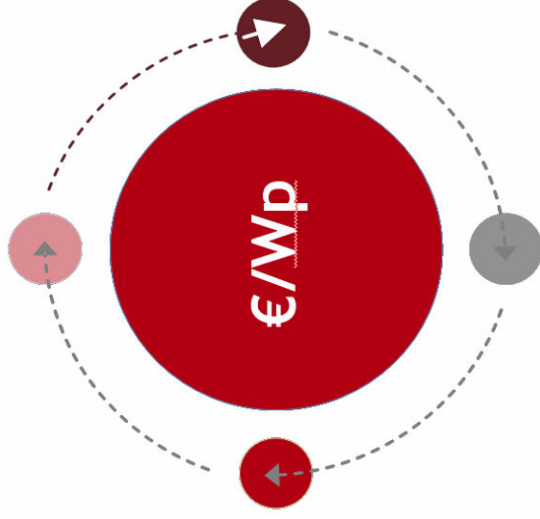


Equipment
Development (COO)

Integrated Turn
Key Solutions

Process
Technology

Device Design
Development





Smart integrated factory:

Processes at the interface between the different factories are merged leading to a truly integrated factory

Major factors for cost reduction in smart integrated factories: Investment

- Reduced investment at interfaces: no packaging, integrated manufacturing equipment, reduced effort in QC (outgoing/incoming inspection)

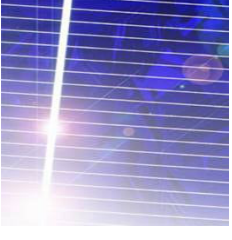
Lower work force number

- Reduced packaging, storage, QC

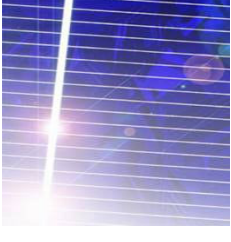
Decreased overall material loss

- No material loss by shipment/packaging
- Optimized process flow over the full value chain

Potential for reduction in manufacturing cost: 6 to 10%



**Grid parity can be reached soon
with crystalline Si PV and! Thin Film**



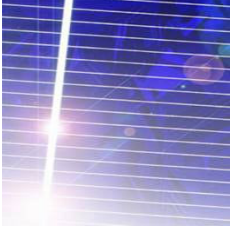
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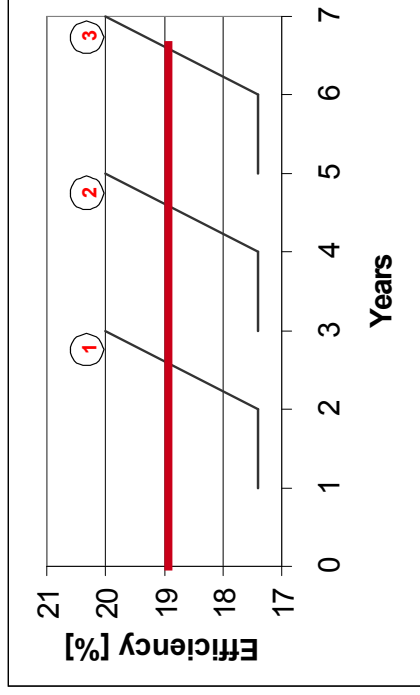
Part 2: Cost Reductions Driven by Technology Advances Solar Cell Production as an Example

- **Cost of Innovation**
- **Revolution**
- **Evolution**



Revolution

- Develop high efficiency production technology starting from a proprietary technology on lab-status



- 1
- 2
- 3

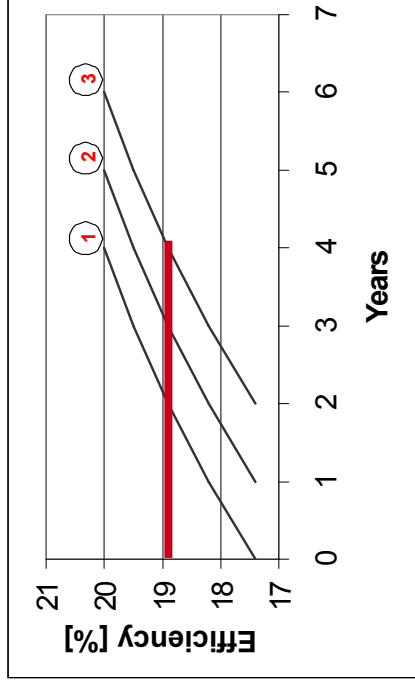
Laboratory

Pilot Line

Mass Production

Evolution

- Step by step development of improved technology towards high efficiency

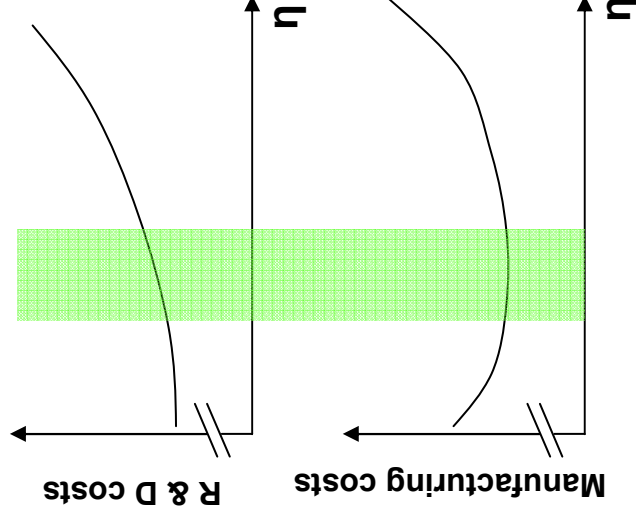


- Possibly unique/ proprietary technology
 - Larger technological risk, even total failure
 - Need to wait until termination of each project phase
 - Typically longer ramp up time
- Stepwise transfer of improved technology into production line
 - Soft learning curve
 - Transfer to production well regulated
 - Financial risk splitted over years



Roadmap solar cell efficiency – strategy

- Centrotherm is more in favor of fast evolution in process technology – rather than revolution for highest efficiency
- Fast Evolution is only possible in production lines running at capacity – stepwise transfer of improved technology
- Best efficiency goal not the highest one technical feasible
- General trend in PV: Successful key innovation needs more and more budget (company size!) (20% technology min: 50M Euro)



Evolution splits financial risk over years
Evolution means early return on investment



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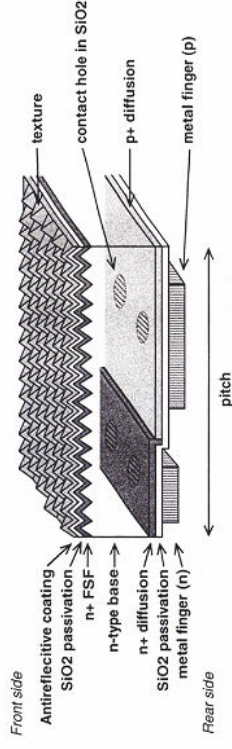
- Cost of Innovation
- **Revolution**
- Evolution

Revolutionary Approaches



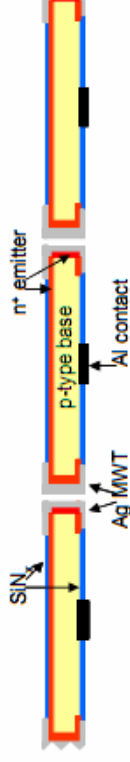
Interdigitated Back Contacted Solar Cells

Sunpower, USA (mass production)



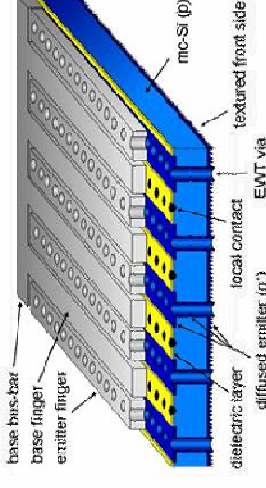
Metallization Wrap Through (MWT) Solar Cell / Pin up modules

ECN NI, Solland NI/D, Arise CDN/D, IMEC (pilot level)



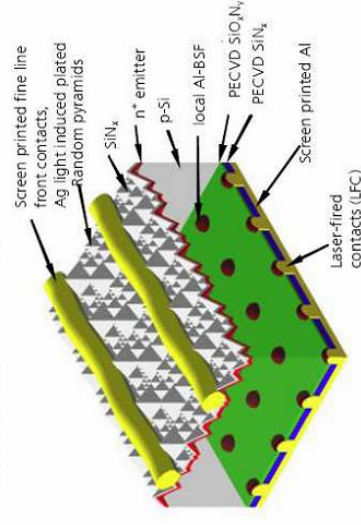
Emitter Wrap Through (EWT) Solar Cells

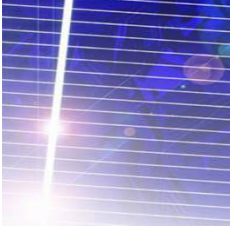
Advent Solar USA, (Q-Cells, Fhg ISE, ISFH D), others (pilot level)



Laser Fired Contact (LFC) Solar Cells

Fhg ISE D (pilot level)
i-PERC/L Solar Cells
 UNSW AUS, IMEC B (Lab type), Suntech (prod.)
HIT Solar Cells and, and, and
 Sanyo JP (production)





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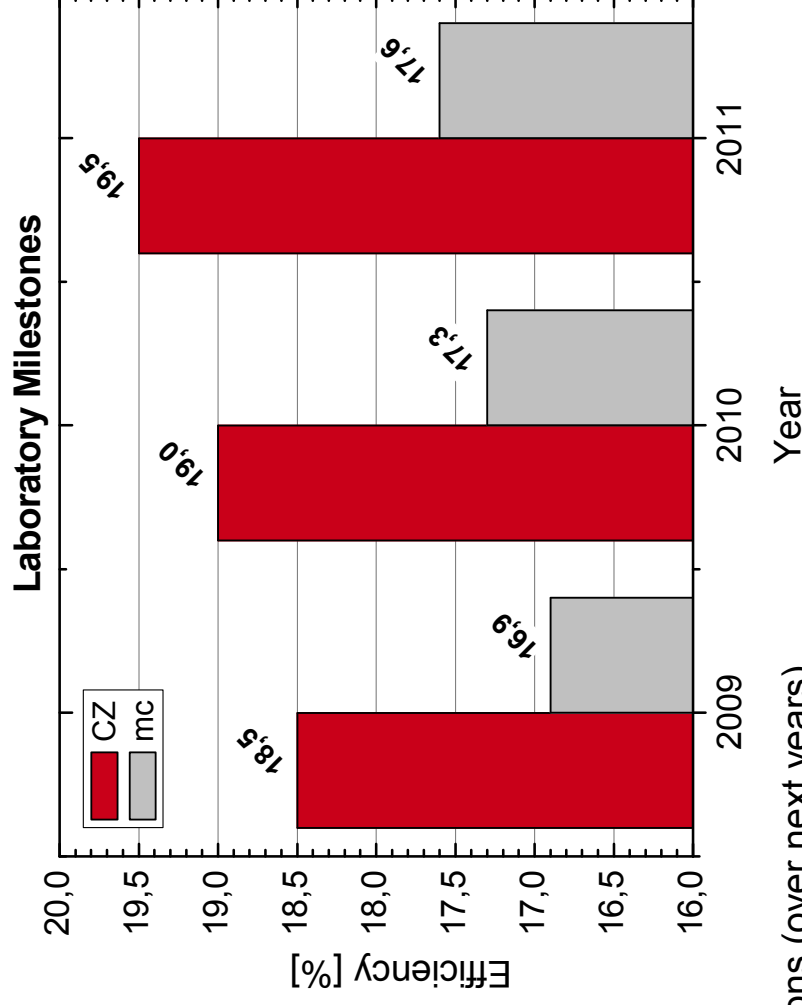
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- Cost of Innovation
- Revolution
- **Evolution**

Evolution: R&D Lab Milestones centrotherm



- 2009 (Phase 1)
new front side +
new back side
- 2010 (Phase 2)
new metallization +
emitter optimization
- 2011 (Phase 3)
total process optimization
- Different process sequences
for mc and CZ from
new back side on
- Wafer thickness above 150 microns (over next years)



How to implement the improvements in existing production lines?



Centrotherm's FlexLine Plus concept

Target: Efficiency of 18% Cz (16.6% mc) by adding selected single equipment for selective emitter formation. No change at the rear side. Lower cost per Wp. Turnkey product available since 2009.

Process:

Saw damage etch and texturing

Dielectric layer generation

Laser patterning

Laser damage removal

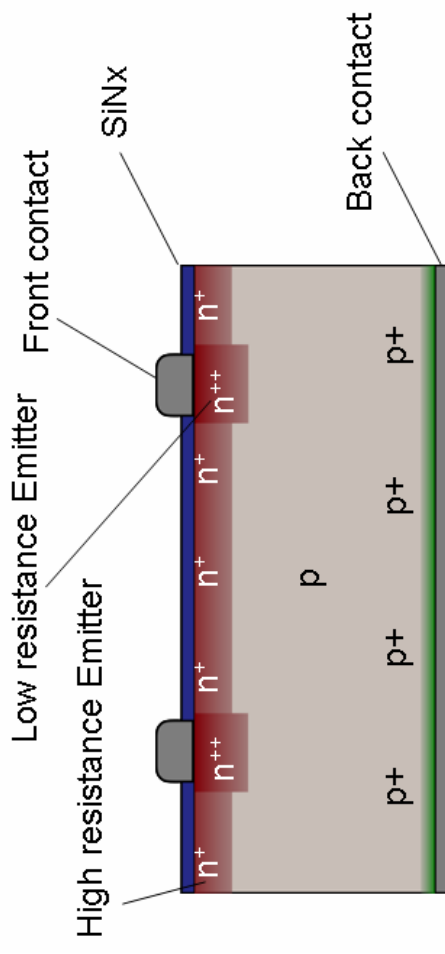
Emitter diffusion

PSG removal

PECVD ARC front

Front, rear metallization

Contact firing

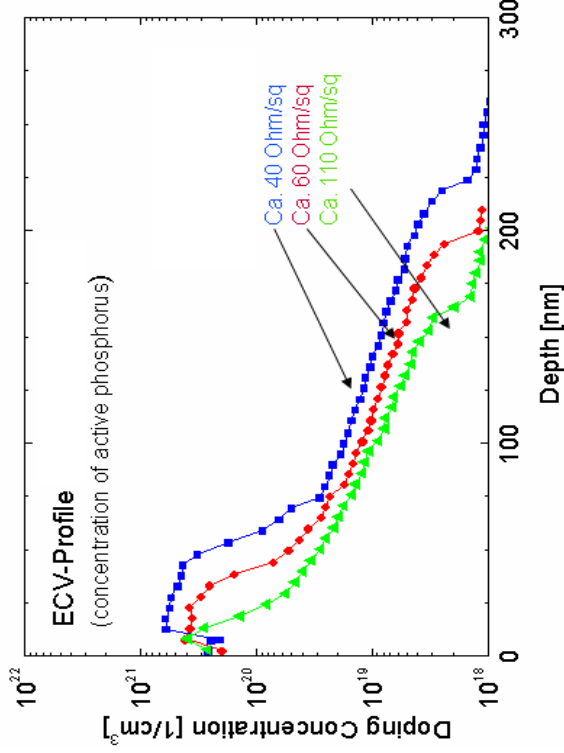
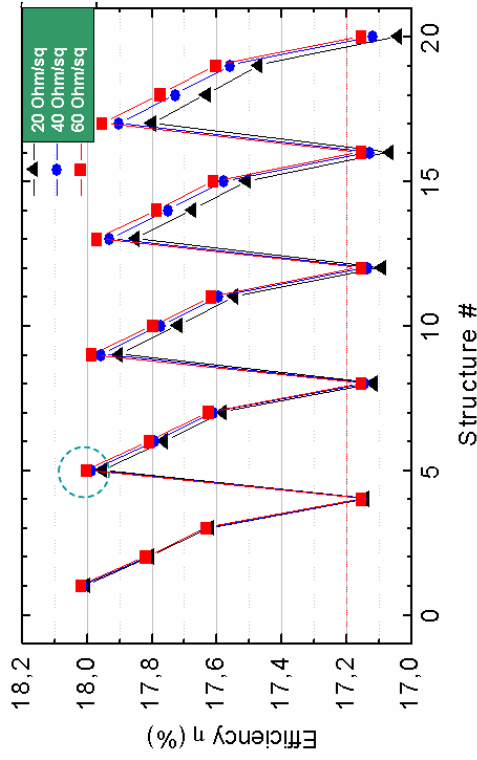
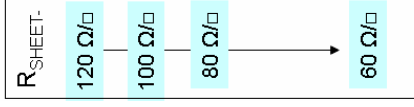
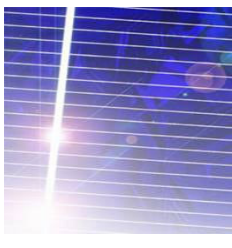


Maximum solar cell values:

Efficiency (%):	18.2
Voc (mV):	634
Isc (mA/cm ²):	36.7

@ 151 cm² Cz

Selective Emitter Simulation



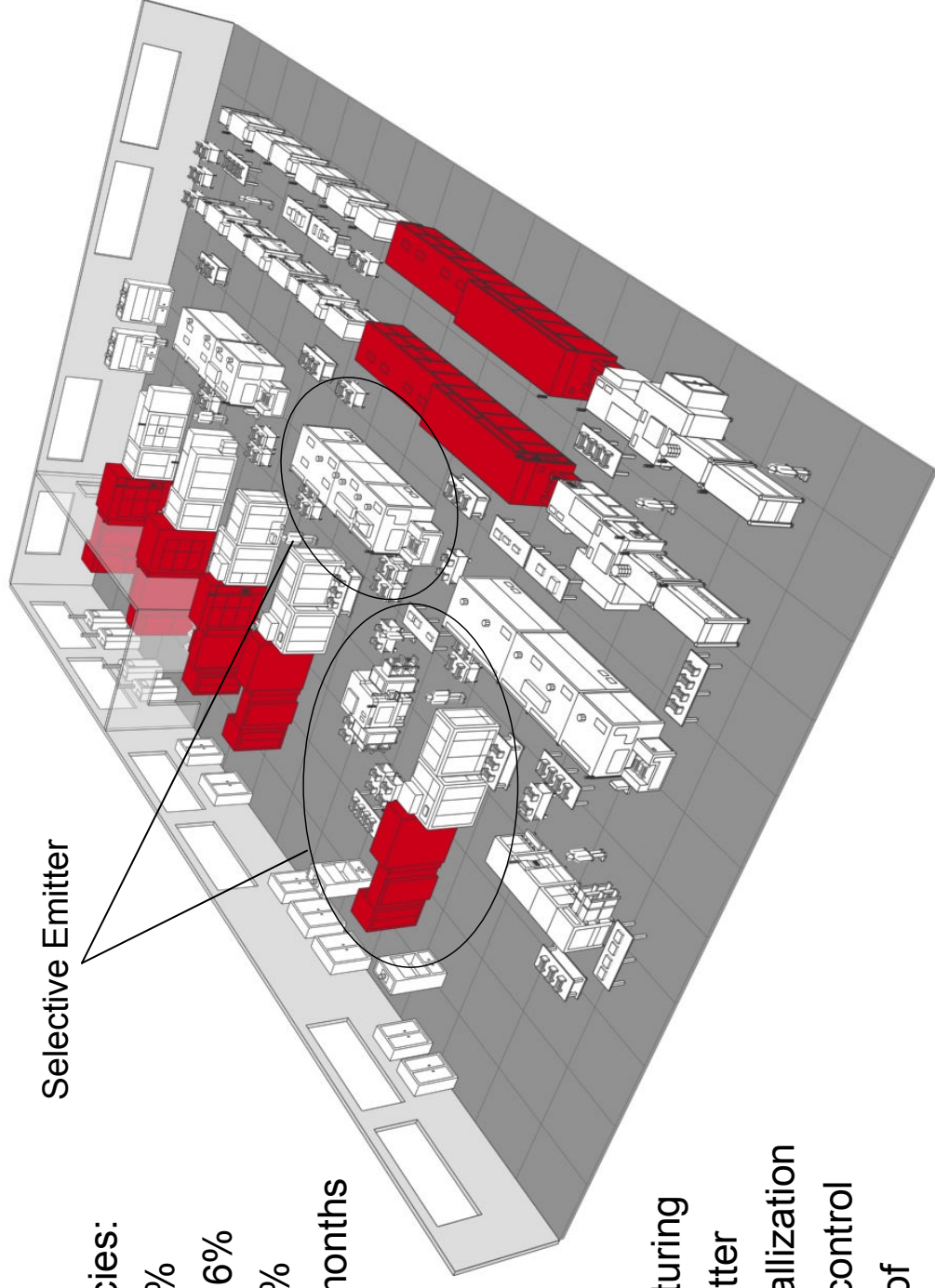
- Let's fix the reference point:
 J_{01} of good industrial reference cells:
 approx. 1000-1200 fA/cm² with $J_{0e} \approx J_{0b}$
- For high ohmic emitters:
 contribution of S_{front} to J_{0e} is significant higher than
 the Auger recombination in the bulk of the emitter
- With a perfect emitter ($J_{0e}=0$):
 $J_{01\text{basis}}$ limits $V_{oc} \leq 638.5 \dots 640.5\text{mV}$
- Assuming FF = 78%, JSC = 37 mA/cm²
 leads to $\eta \approx 18.5\%$
- Taking into account highly doped areas with 45 Ω/\square
 $\Rightarrow \eta \approx 18.3\%$.
- Adding $J_{0e} \approx 100\text{-}150\text{ fA/cm}^2$
 $\Rightarrow \eta \approx 18.15\%$
 $\Rightarrow V_{oc} \approx 634\text{mV}$
- $\Rightarrow \Delta V_{oc} \approx 15\text{ mV}$ compared to reference
 $\Rightarrow \Delta \eta \approx 0.6 - 0.7\%$ abs.

Turn Key Production Line: FlexLine Plus



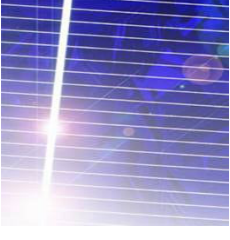
Layout FlexLine Plus

- Output: >60MW
- Guaranteed Efficiencies:
 - Mono Si: 18%
 - Multi Si: 16.6%
- High yield: 96%
- Ramp up time: 6 months

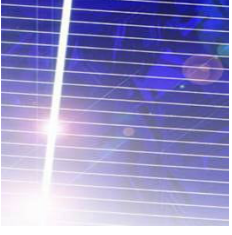


- Process features:
 - Improved texturing
 - Selective emitter
 - Fine line metallization
 - Tight quality control
 - High degree of automation

Conclusion

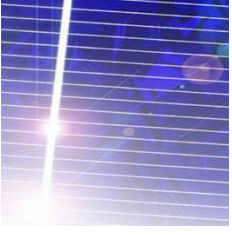


- Grid parity can be reached soon with crystalline Si PV and! Thin Film
- Evolution increases efficiency continuously, faster in production line
- Significant progress reached in cell technology in past year



Thank you for your attention!

Appendix





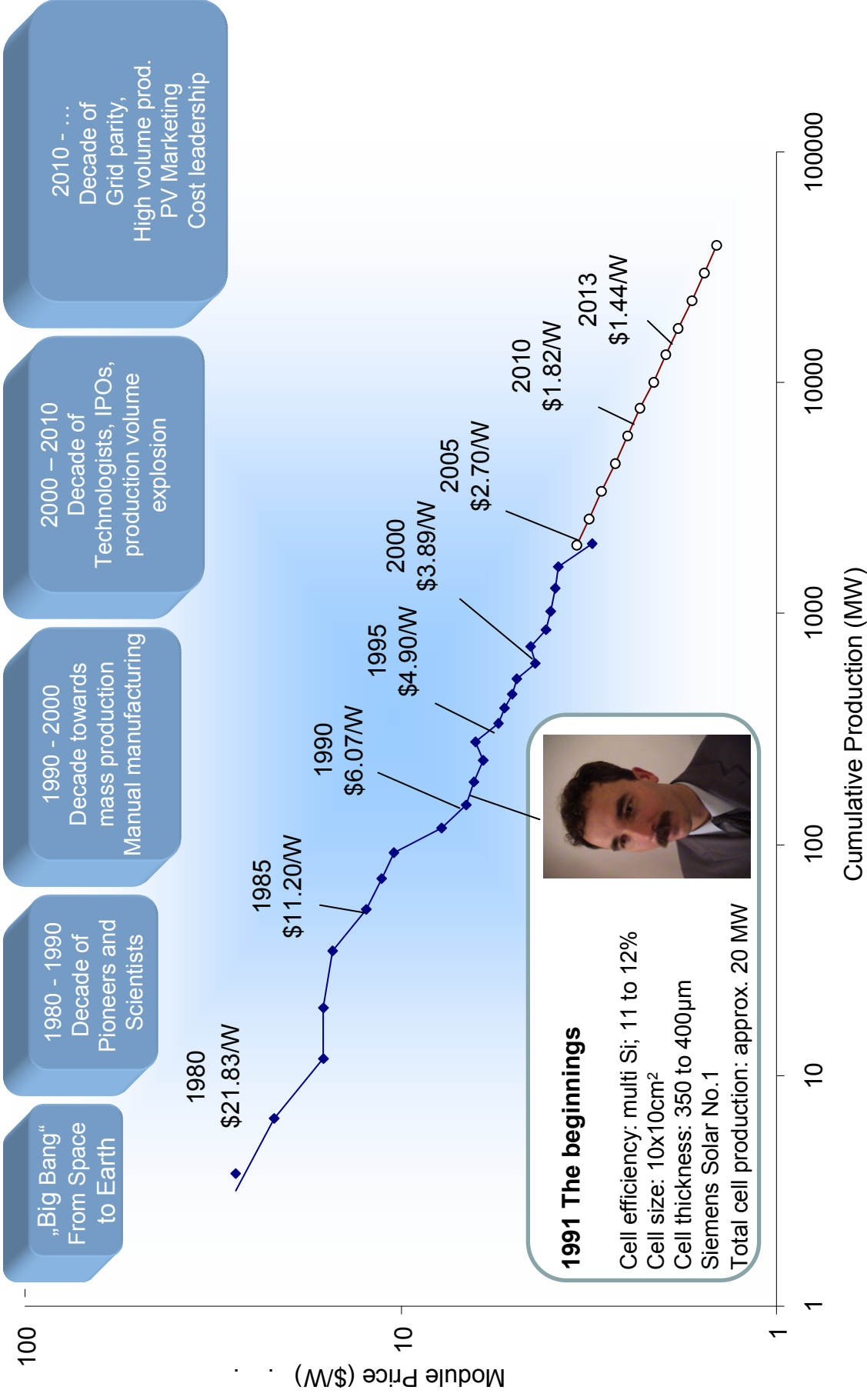
Crystalline Silicon versus Thin Film Technology

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- Grid parity with Crystalline Silicon

Solar cell production

- Introduction
- Cost of Innovation
- Revolution
- Evolution

Peter's little PV history



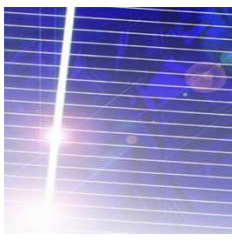
2010 - ...
 Decade of
 Grid parity,
 High volume prod.
 PV Marketing
 Cost leadership

2000 - 2010
 Decade of
 Technologists, IPOs,
 production volume
 explosion

1990 - 2000
 Decade towards
 mass production
 Manual manufacturing

1980 - 1990
 Decade of
 Pioneers and
 Scientists

**„Big Bang“
 From Space
 to Earth**



Material outlook



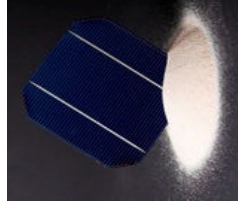
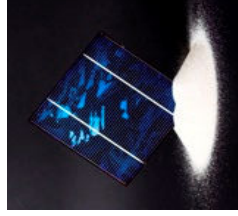
Current status:

- Slightly increasing share of mono Si
- Caused by the availability of mono Si technology and equipment at fast growing key manufacturing countries (such as China, Russia, etc)
- Trend not linked to reduced manufacturing cost of mono Si cells

Outlook:

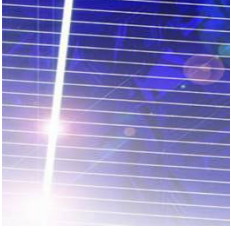
- In future (3 to 5 years) increasing specialization in PV industry:

**Low cost high
throughput multi Si cell
production technology,
based on lower quality,
cost of feedstock and
wafer material**

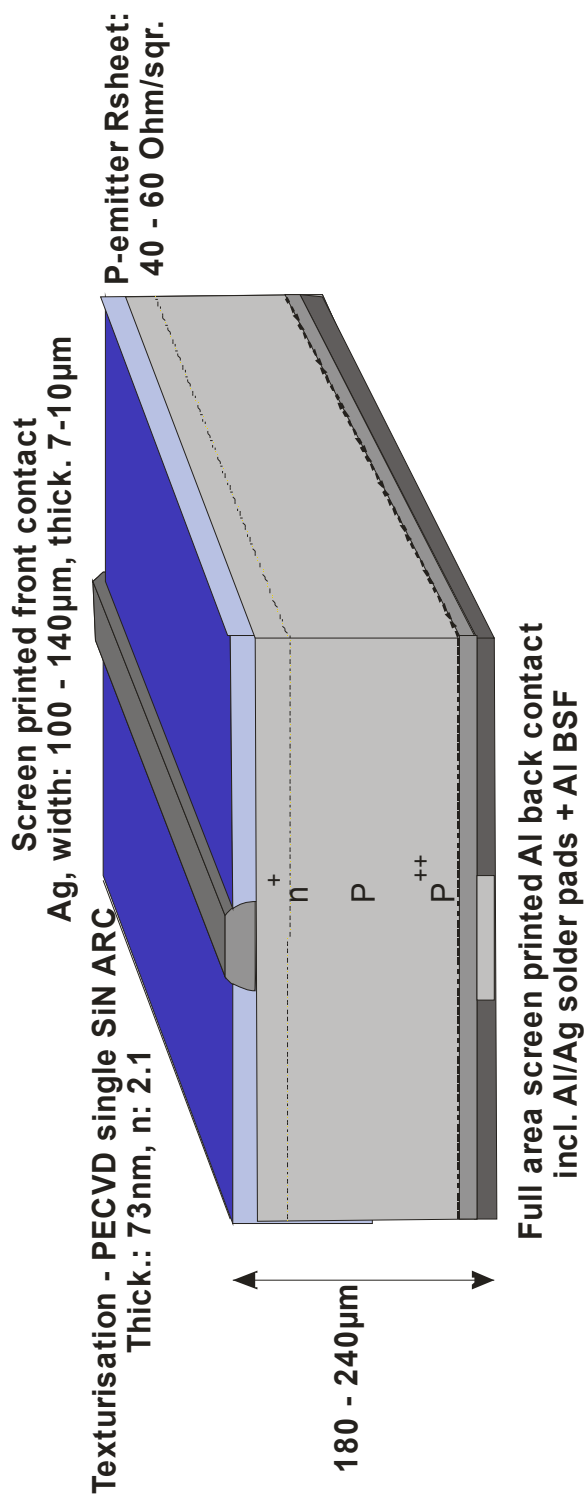


**High efficiency mono Si
cell technology using
best wafer and
feedstock (Siemens)**

The race is open!



Typical industrial Si solar cell



- Device structure of nearly 100% of all multi Si and 75% of all mono Si solar cells
- Not changed in the past 5 years except wafer thickness

Status: Cell line key performance indicators



Efficiency

Average

Multi 14.5 ↔ 16,2% (av. 15.5%)

Mono 14.5 ↔ 21% (av. 16.5%)

Yield

Mechanical/electrical loss

(high material quality):

3 to 5%

optical loss: 2 to 3%

Throughput

750 - 2400 pieces/hour

> 3000 pieces/hour (next 3years)

Capacity per line

15 to 65MW/a

Capacity utilization

25% to 100%

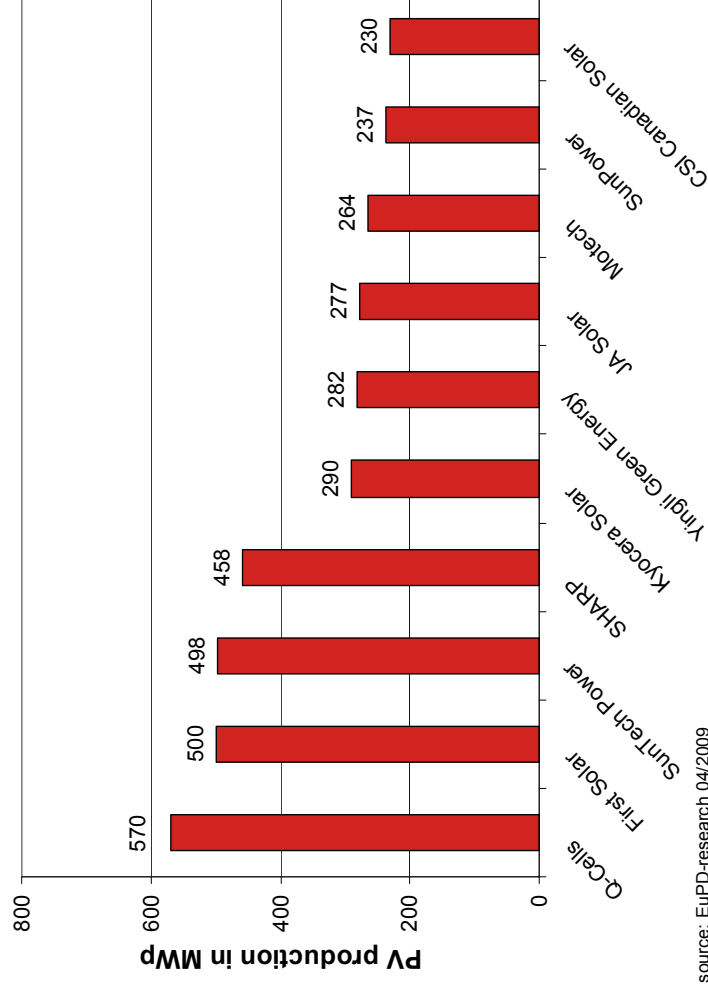
Average: ca. 60% to 70%

Production concept

Inline (share: ca. 25-30%)

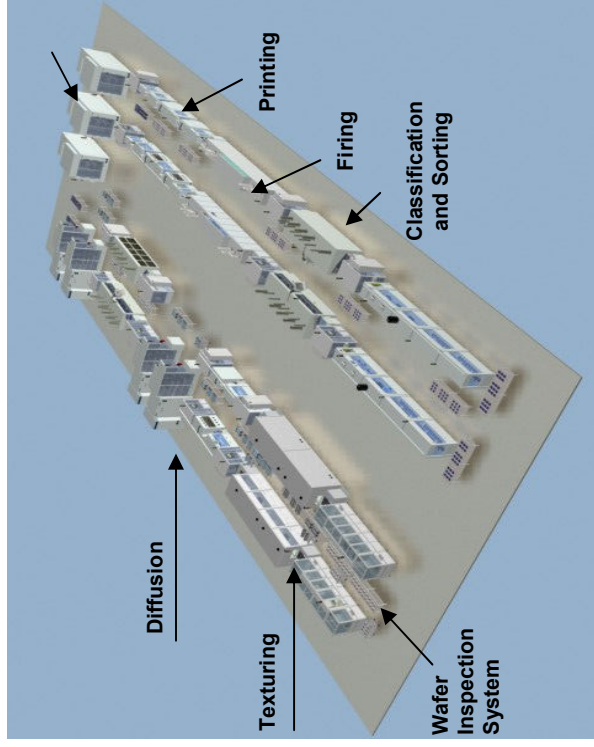
Batch (share: ca. 70-75%)

Top 10 PV production companies in 2008



source: EuPD-research 04/2009

Solar cell factory: 100 MW example



- 2 solar cell lines (>50MW_p each)
- Space: 5.000 m²
- Material: multi Si
- Efficiency: 15.8- 16.2%
- Production of ca. 100 MW_p / a
- Production costs 1,09 €/cell (0,28 €/W_p) in Germany

- Equipment: 35 Mio. €
- Building 10 Mio. €
- Production goods
 - Paste front 0.05 g/Wp
 - Paste rear Ag 0.04 g/Wp
 - Paste rear Al 0.42 g/Wp
- Running cost
 - Electricity 0.21 kWh/Wp
 - Utilities 0.02 €/Wp
- Workforce 108 person

